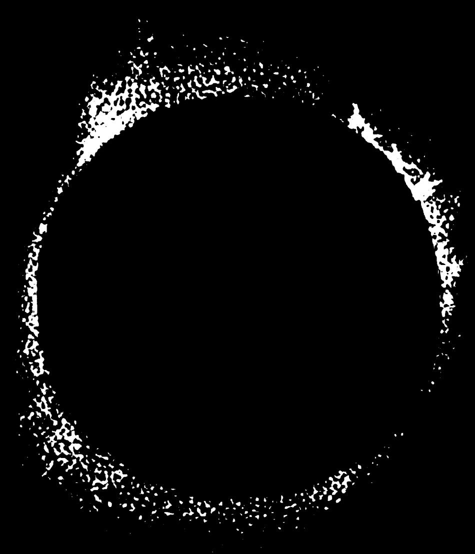


The Astrophysical journal

American Astronomical Society, University of Chicago

The Astrophysical Journal

THE

ASTROPHYSICAL JOURNAL

An International Review of Spectroscopy and Astronomical Physics

VOLUME XII

JUNE—DECEMBER, 1900

CHICAGO
The University of Chicago Press
1900

PRINTED BY
The University of Chicago Press
CHICAGO

CONTENTS

NUMBER I.

NUMBER II.

NUMBER III.

NUMBER IV.

NUMBER V.

THE

ASTROPHYSICAL JOURNAL

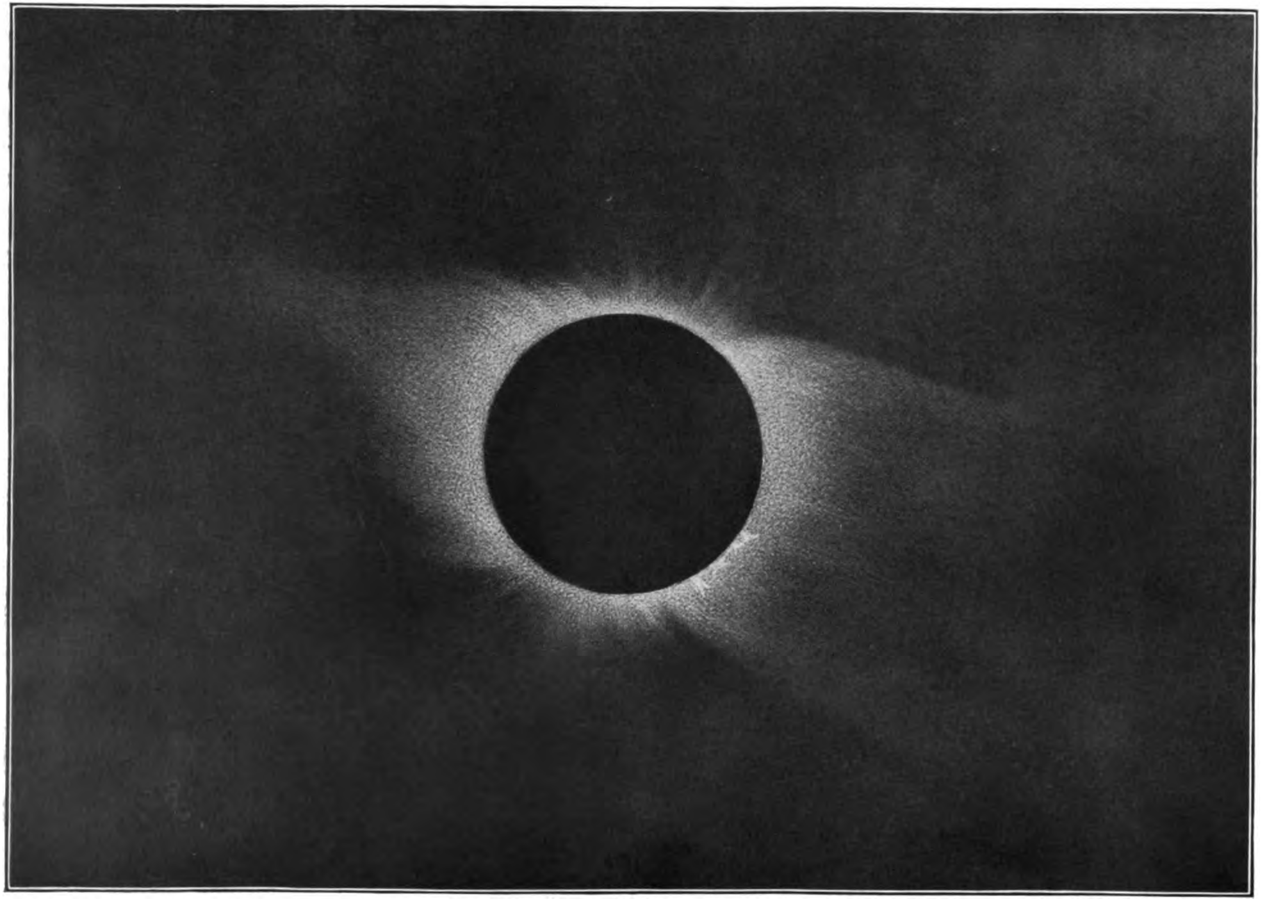
AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOL. XII JULY, 1900 NO. 1

The ASTROPHYSICAL JOURNAL is published monthly except in February and August. Annual subscription, $4.00; foreign, 18 shillings. *Wm. Wesley & Son, 28 Essex Street, Strand, London*, are sole foreign agents and to them all European subscriptions should be addressed. All papers for publication and correspondence relating to contributions and exchanges should be addressed to *George E. Hale, Yerkes Observatory, Williams Bay, Wisconsin, U. S. A.* All correspondence relating to subscriptions and advertisements should be addressed to *The University of Chicago Press, Chicago, Ill.* All remittances should be made payable to the order of the *University of Chicago*.

[Entered at the Post Office at Chicago, Ill., as second-class mail matter.]

PLATE I



THE CORONA

Drawn from Photographs by P. R. Calvert

THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME XII JULY, 1900 NUMBER 1

ON THE SPECTRUM OF RADIUM.

By C. RUNGE.

M. AND MME. CURIE have discovered that certain substances prepared from pitch blende possess the remarkable property of emitting Becquerel rays. There is good reason to believe this property to be connected with the existence of at least one new element. For in the spectrum of one of these substances M. Demarçay has found a number of lines, which cannot be identified with any known lines.[1] I think, however, that his determinations of the wave-lengths can hardly be considered sufficiently accurate for the purpose of identification, and I have therefore tried to determine the wave-lengths with greater precision. Dr. F. Giesel kindly gave me a preparation that he has made of the substance in question. The new element is present only in very minute quantities, for it has not yet been possible to prove its existence by any chemical means. Apart from the new element the substance consists of chloride of barium. Of M. Demarçay's fifteen radium lines I could not observe more than three. The remaining twelve either do not appear, or they so nearly coincide with lines which I observed in the spectrum of pure chloride of barium, that I could not convince myself of their existence. I do

[1] DEMARÇAY, *C. R.*, 129, 717, 1899.

not want to imply that these lines in M. Demarçay's list do not belong to the new element. I merely wish to say that I have not been able to check his observations of them. It may be that M. Demarçay produced the spectrum in a different manner, thereby getting rid of the lines, which in my comparison spectrum of pure chloride of barium take the place of the radium lines. The following list contains M. Demarçay's determinations as well as mine, together with some remarks on the different lines:

Runge		Demarçay		Remarks
Wave-length	Mean error	Wave-length	Intensity	
		3649.6	12	Also in $BaCl_2$.
3814.591	0.016	3814.7	16	
		4340.6	12	Not seen.
		4364.2	3	" "
		4436.1	8	" "
		4458.0	3	" "
		4533.5	9	" "
		4600.3	3	Also in $BaCl_2$. Kayser and Runge: *Ba* 4600.02
		4627.4	4	" " " " " " 4628.45
		4641.9	4	" " "
4682.346	0.009	4683.0	14	
		4692.1	7	" " " " " " 4691.74
		4699.8	3	" " " " " " 4700.64
		4726.9	5	" " " " " " 4726.63
4826.14	0.06	4826.3	10	

The relative intensities of the three lines which I have observed agree with the estimations of M. Demarçay. His absolute intensities have probably been greater. That would explain why he has seen lines that did not appear in my spectrum. I cannot, however, explain why the lines 4340.6, 4436.1, 4533.5, to which he assigns the intensities 12, 8, 9, were not seen by me, as the line 4826 (intensity 10) is clearly visible.

In the second column I have added the mean error of my determinations. The first line was only photographed in the first order of a grating of 1 meter radius and about 50,000 lines. The second and third lines have also been photographed in the first order of a large grating of about 6 meters radius and 110,000 lines. The third line has also been photographed in the second order of the small grating. The wave-lengths were interpolated

partly from barium lines, partly from iron lines. Iron wire was for this purpose substituted for the platinum wire carrying the substance. I have photographed the spectrum from 6000 A. U. to 2400 A. U. The red part of the spectrum was examined visually.

The three lines are not among the Fraunhofer lines measured by Rowland. 4826.14 falls between 4825.907 and 4826.554; 4682.346 between 4682.295 *Fe?* and 4682.529 *Co;* 3814.591 between 3814.500 *C* and 3814.671 *Fe-C.*

The platinum wire which was to carry the substance to be investigated, was doubled up and twisted into a loop. By letting an electric current flow through the wire it was heated sufficiently to make the substance stick to the loop and melt together. This is a far more economical way of fixing the substance to the wire than by heating it in a Bunsen flame. I could make a series of exposures and an elaborate examination of the red part of the spectrum with not more than 0.1 gram. At the same time this arrangement serves to heat the substance during the exposure, which materially increases the intensity of the spectrum. I have to thank Professor Paschen for suggesting this device. The substance was taken as anode. The kathode is then also heated by properly adjusting a second spark-gap interposed in the circuit. In this way the air lines may be gotten rid of.

I have also heated the radium preparation *in vacuo* in order to search for an unknown gas. The spectrum was that of chlorine with some sulphur lines showing as an impurity, but no new lines were observed. Another preparation with similar physical properties containing the hypothetical element "Polonium," which I also owe to the kindness of Dr. Giesel, was investigated in the same manner. But neither the spark spectrum nor the spectrum of the vacuum tube, when the substance was heated in it, showed any new lines.

The three radium lines, of which I have given the wavelengths, appeared also in a preparation of barium bromide which Dr. de Haen had the kindness to give me.

TECHNISCHE HOCHSCHULE, HANNOVER,
May 1900.

THE VELOCITY OF METEORS AS DEDUCED FROM PHOTOGRAPHS AT THE YALE OBSERVATORY.

By W. L. Elkin.

The instruments in use at the Yale Observatory for the photographic observation of meteors (see this Journal 9, 20) have been equipped with an arrangement for the determination of the velocity of the meteors. The idea of using photography for this purpose seems to have first been suggested as long ago as 1860 by J. Homer Lane, the well-known physicist and discoverer of "Lane's Law." In 1885 a well-planned attempt in this direction was made by Zenker, in Berlin, on the occasion of the expected shower of Andromedids, but without success, apparently. And lately the suggestion has been again made by Professor Fitzgerald.

The Yale apparatus consists of a wheel (a bicycle wheel) rotating in front of the cameras and carrying a number of opaque screens. There are at present 12 of these interceptors and the rotation is effected at the rate of 30 to 50 turns a minute by means of a small motor worked by 3 or 4 bichromate cells. It will be advisable to increase the number of occultations in future, however. At each revolution a record is made on the chronograph, so that the wheel's velocity at any instant is always known.

The length of the interruptions of a meteor trail and the resulting velocity are easily derived from the plates, of which Fig. 1 shows the first such divided-up trail secured (on July 31, 1899), if the meteor is also recorded on a plate at our second station at Hamden, distant about 3 km. The first attempt was made at this August period last year, and subsequent ones at the Leonid, Andromedid, and Geminid epochs in November and December last. In all, so far five such trails have been obtained with corresponding records at Hamden and the time and identification also secured. These have now been carefully measured

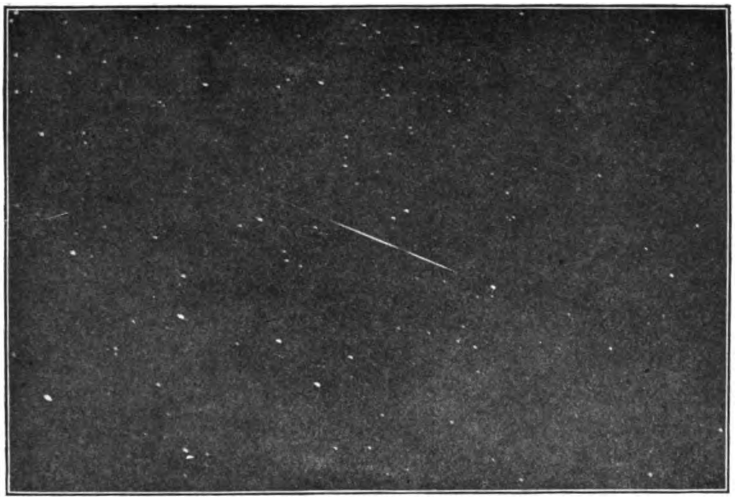


FIG. 1.

and reduced and the resulting data are brought together in the following table, of which the headings explain themselves sufficiently:

Meteor No.	Date 1899	Greenwich mean time	Apparent radiant 1875.0 R. A. Decl.	Apparent velocity (km per sec)	Approximate altitude (in km)
1	July 31	$17^h\ 4^m\ 30^s$	$28°\ 55' + 57°\ 31'$	50.4	From 88 to 75
2	Aug. 7	14 25 25	288 12 − 6 20	12.2	50 45
3	Aug. 8	16 32 47	43 55 +56 33	50.3	101 94
4	Nov. 24	16 31 25	27 43 +40 33	20.2	93 90
5	Dec. 12	21 43 0	113 44 +33 36	36.5	90 86

If we now correct the values for the apparent radiant and velocity for the effect of the attraction of the Earth and its diurnal rotation by Schiapparelli's formulae, we derive the "corrected" radiant and velocity in the following table, and hence the "true" velocity of the meteor relative to the Sun. The last columns of this table contain the "true" and "apparent" velocities which a parabolic orbit or, in the case of the November 24 meteor, an elliptic orbit of 6.62 years period should have produced.

Meteor No.	Corrected radiant, 1875.0 R. A.	Decl.	Corrected apparent velocity (km per sec.)	True velocity (km per sec.)	Parabolic or elliptic velocity (km per sec.) true	apparent
1	29° 50′	+57° 40′	49.1	34.4	41.8	58.3
2	289 44	−27 58	5.0	32.0	41.8	27.1
3	45 12	+56 35	49.0	32.4	41.8	60.3
4	23 52	+39 46	16.8	39.8	39.3	19.6
5	112 22	+33 2	34.7	34.0	42.4	49.5

A comparison of these last two columns with the corresponding ones of the observed values shows that, except in the case of the Andromedid meteor on November 24, both the apparent and true observed values of the velocity are much smaller than those derived on the assumption of a cometary velocity. The former (the observed) velocities lead to orbits of a very improbable character, having periods of from 1.25 to 1.80 years, so that it would seem an almost certain conclusion that the atmospheric retardation has amounted to from 8 to 15 km per second for the four meteors. On the other hand, the Andromedid on November 24 furnishes the following orbit, by the side of which is placed that of Biela's comet according to Hubbard;

$$\text{Meteor Nov. 24, 1899:}\left\{\begin{array}{l} \left.\begin{array}{l} \pi = 108^\circ\ 48' \\ \Omega = 242\ \ 22 \\ i = \ \ 12\ \ \ \ 4 \end{array}\right\} 1875.0 \\ e = 0.7923 \\ a = 4.110 \end{array}\right.$$

$$\text{Biela Comet:}\left\{\begin{array}{l} \left.\begin{array}{l} \pi = 109^\circ\ \ 8' \\ \Omega = 245\ \ 51 \\ i = \ \ 12\ \ 33 \end{array}\right\} 1852.0 \\ e = 0.7559 \\ a = 3.526 \end{array}\right.$$

Rather unfortunately this Andromedid trail is at the very edge of the plate and therefore somewhat ill-defined, so that the length of the single interruption available is somewhat uncertain. If this be changed by 19″ from the original measurement, or about one fifteenth of a millimeter on the plate, a quantity which perhaps is admissible under the unfavorable circumstances, an

exact agreement with the cometary elements *a* and *e* can be brought about.

This remarkable circumstance makes it therefore again somewhat questionable whether the small velocities found for the other four meteors may not after all be somewhere near the cosmic values and the truth will have to await accumulated evidence. Especially valuable will be a long trail with considerable change in altitude and a large number of sharp interruptions. The only one of our trails which has more than two such breaks is the one on August 7, where three values of the velocity can be deduced. These are, in the order of the meteor's progress and descent, 12.33, 12.11, and 12.09 km per second, which, while showing an increase of retardation, hardly admit of any very definite conclusion. As I have just said, more data are necessary and these we hope to secure and also increase their accuracy in the near future.

SOME NEW FLUORESCENCE AND AFTERGLOW PHENOMENA IN VACUUM TUBES CONTAINING NITROGEN.

By Percival Lewis.

I. FLUORESCENCE.

While investigating the effect of impurities on the spectrum of nitrogen, I observed sôme peculiar fluorescent and afterglow effects, which appear to be due to the presence of exceedingly small traces of oxygen or water vapor, and which apparently have not been previously described.

The nitrogen was chemically prepared by heating a solution of ammonium sulphate and sodium nitrite. The gas was freed from oxygen by passing it through a solution of pyrogallol. Sometimes the conditions were varied without change of the results, by passing it over heated copper. It was then carefully dried by passing it through concentrated sulphuric acid and a series of tubes containing calcium chloride, caustic potash, soda lime, and phosphorous pentoxide.

The vacuum tube usually employed was of the end-on type, with a quartz window, and could be used with either internal or external electrodes.

After pumping out and admitting first nitrogen, a remarkable fluorescence was observed during a few seconds after first closing the current. This fluorescence (which I shall call "β-fluorescence") was not limited to the path of the discharge, as in the case of the ordinary ("α") fluorescence, but was visible for some distance on each side of the electrodes where no discharge could be seen. This fluorescence flickered unsteadily for several seconds, then died away, first in the capillary, then in the more distant parts of the tube. The weaker the current, the longer the phenomenon lasted. It persisted steadily during the passage of a slow current of fresh nitrogen through the tube,

and was visible at pressures as high as 15 or 20 centimeters. At such pressures the phenomenon was often confined to the region of the electrodes, no visible discharge passing between them. If the tube was filled with fresh gas and the current rapidly turned on and off, the fluorescing regions could be seen gradually receding into the supply and exhaust tubes, as though some progressive change, due to the current, was taking place.

It was really fluorescence of the gas, not any direct radiation from the gas. This was proved by heating a portion of the tube. On admitting a slow stream of nitrogen, the tube did not fluoresce at the heated portion, although it did so strongly on both sides. The β-fluorescence gives a brilliant opalescent blue-green light, comparable in intensity with the fluorescence excited by cathode rays.

When the nitrogen was not freed from the last traces of oxygen, the β-fluorescence was considerably weaker. The addition of very small quantities of oxygen, hydrogen, water vapor, or carbon dioxide weakened or destroyed it.

It seemed possible that the fluorescent condition might be made permanent by complete drying and removal of every trace of oxygen. The most careful attempts in this direction failed to increase the duration of the phenomenon in the slightest degree. It seemed probable, therefore, that the β-fluorescence is not a property of absolutely pure nitrogen, but is due to small traces of some impurity or to chemical action.

In nitrogen prepared from air by passing through pyrogallol, and over hot copper and phosphorus, only the ordinary α-fluorescence could be seen. If, in addition, the air was allowed to rest some time in contact with copper turnings moistened with ammonia (a method strongly recommended by Threlfall[1]), a very feeble β-fluorescence could be seen. Either the oxygen had not been completely removed, or argon and other constituents of the air hindered the effect. The ordinary fluorescence was especially strong in air nitrogen, but it was not so strong as the β-fluorescence, was confined to the region

[1] THRELFALL, *Phil. Mag.*, (5), 35, 1, 1893.

between the electrodes, and was diminished, not increased, during the passage of a current of fresh gas.

Morren[1] has described a very brilliant fluorescence which he observed in nitrogen tubes containing mercury vapor, which he ascribed to the ultra-violet radiation of the mercury. In my experiments the mercury vapor was usually excluded by a sulphuric acid valve. Its admission seemed to have no effect on the phenomenon.

It seemed certain that the β-fluorescence was due to some kind of radiation which the nitrogen emitted only during certain temporary conditions; therefore a complete investigation of the spectrum was undertaken.

During fluorescence the intensity of the entire visible spectrum was considerably diminished. No other change could be detected. Since steady fluorescence could only be obtained during the passage of a stream of fresh gas, involving change of luminosity due to the change in pressure, photometric measurements were difficult. It was roughly estimated, however, that the reduction in intensity during the β-fluorescence was certainly more than one half. At very high pressures the visible discharge disappeared almost completely.

An investigation of the ultra-violet region was next undertaken. The tube was provided with a quartz window, and by means of a quartz prism and lenses a short spectrum was thrown on a bariumplatinocyanide screen. Under ordinary conditions, when the current passed, a short visible spectrum and five bright fluorescent bands in the adjacent ultra-violet could be seen on the screen, with a very feeble and diffuse fluorescence in the extreme ultra-violet. When fresh nitrogen was admitted, the β-fluorescence took place, the visible spectrum vanished almost completely, and a number of bright bands flashed out with a maximum intensity far in the ultra-violet. When the stream of gas was cut off, the spectrum resumed its original appearance.

Photographs of the ultra-violet region were then taken under different conditions. In each case the time of exposure was

[1] MORREN, *Ann. Chim. et Phys.* (4), 4, 296, 1865.

two minutes, and corresponding pairs were taken respectively during and after the β-fluorescence, at an average pressure of 2 cm, and with the same current in each case. It was, of course, impossible to focus on all parts of the spectrum simultaneously, and after necessary disturbances of position it was impossible to reproduce the adjustments exactly; therefore all parts of the same photograph are not equally sharp, and no two sets of photographs show the bands in exactly coincident position. The wave-lengths of the edges of the bands were determined by comparison with the spectra of cadmium and zinc and with the map given by Deslandres.[1]

Below are data referring to the photographs obtained.

I. With internal electrodes and feeble current. (1) During β-fluorescence. The bands of wave-length 260, 248, and 237 $\mu\mu$ are the most intense. The visible spectrum fails to make any impression on the plate. (2) After the β-fluorescence had ceased. A portion of the visible spectrum can be seen, and the most intense bands are those of wave-length 358 and 337 $\mu\mu$. The bands in the extreme ultra-violet are much weaker. There are bands at λ227 and λ215 $\mu\mu$, which made scarcely any impression on the plate.

II. External electrodes. Similar effects are observed, but the contrast is even stronger than when internal electrodes were used. In some photographs the extreme ultra-violet bands could not be seen at all except during β-fluorescence.

III. Nitrogen from air. The entire spectrum is more intense, as a stronger current was used. Otherwise there is no apparent difference from I (2).

IV. A Tesla coil was used. The contrast between the two conditions of the nitrogen is strongly shown.

V. In order to certainly remove all traces of oxygen and water vapor metallic sodium was sealed in the tube and heated. No β-fluorescence could then be obtained, and the extreme ultra-violet bands almost disappeared, as shown in the last pair of

[1] DESLANDRES, *Comptes Rendus*, 101, 1256, 1885; *Ann. Chim. et Phys.* (6), 5, 46, 1888.

photographs. The first was taken with a slow current of fresh nitrogen passing through the tube, the second with the nitrogen at rest.

The conclusion seems justified that the β-fluorescence is caused by the temporary emission of powerful ultra-violet radiation. It may possibly be due not altogether to the presence of this radiation, but to the absence or weakness of visible radiation. In III the extreme ultra-violet bands are almost as strong as in I (1); but the visible radiation is much stronger, and there is no β-fluorescence.

Deslandres[1] found that the nitrogen spectrum consists of three groups of bands, differing in their physical conduct. The first lies in the visible region, and, according to Deslandres, belongs to pure nitrogen. The second lies between 500 and 280 $\mu\mu$; the third between 300 and 200 $\mu\mu$. He found that after metallic sodium had been introduced into the tube and heated, the third group disappeared, while the second became stronger. He concluded, therefore, that the second group is due to a combination of nitrogen with hydrogen, the third to a combination of nitrogen with oxygen. The water which adheres so persistently to the walls of a glass tube is given off and decomposed by the current, and thus the components of the two combinations are supplied. If sodium be present the oxygen is removed, and the third group disappears.

My experiments and those of Deslandres seem to be closely related. It will be seen that Deslandres' third group coincides exactly with the regions of the spectrum which seem to excite the β-fluorescence. After sodium had been heated in the tube the β-fluorescence disappeared completely. When external electrodes were placed on the supply and exhaust tubes, some distance from the sodium, the glass in the region of these electrodes fluoresced brilliantly during the passage of a current of the fresh gas. It is evident, therefore, that no permanent change in the gas had been caused as it passed the hot sodium. It does not seem likely that any direct action or combination

[1] DESLANDRES, *loc. cit.*

between the nitrogen and sodium could destroy the β-fluorescence, and Deslandres' explanation seems very probably correct. We may assume that infinitesimal traces of the ever-present water are decomposed, and that the combination of the resulting nascent oxygen with the nitrogen takes place with so much energy that the atoms or molecules which take part temporarily emit a disproportionately large part of the radiation. If this be the correct explanation, however, it seems most singular that greater, but still very small, quantities of oygen or water vapor will completely destroy the β-fluorescence. The presence of the small quantity of the oxide of nitrogen formed during the first few seconds of discharge must also destroy the fluorescent action.

II. AFTERGLOW.

Morren,[1] Sarasin,[2] Warburg,[3] and others, have studied the afterglow in nitrogen which is due to the presence of small quantities of oxygen. Usually this phenomenon is described as a whitish, shimmering cloud. Sarasin[4] has also observed a yellow phosphorescence in nitrogen, which he attributed to an oxide of nitrogen. I have found but few references to the spectrum of the afterglow. Using electrodeless tubes, J. J. Thomson[5] found an afterglow in air with a spectrum consisting apparently of lines or bands. Hertz[6] could not obtain any spectrum of the afterglow in nitrogen; in air he observed a continuous spectrum, especially strong in the red, yellow, and green. Goldstein[7] observed a yellow afterglow in air; he makes no reference to its spectrum.

With considerable traces of oxygen in nitrogen I have obtained the white afterglow, with an apparently continuous spectrum. In nitrogen prepared from air, before the oxygen had been completely removed, I have also observed an apple-green

[1] MORREN, *Ann. Chim. et Phys.* (4), p. 293, 1865.

[2] SARASIN, *Pogg. Ann.*, 140, 425, 1870.

[3] WARBURG, *Arch. de Gen.* (3), 12, 504, 1884. [4] SARASIN, *l. c.*, p. 432.

[5] J. J. THOMSON, *Phil. Mag.*, 32, 335, 1891. [6] HERTZ, *Wied. Ann.*, 19, 78, 1883.

[7] GOLDSTEIN, *Verhand. d. deutscher phys. Gesell.*, 1, 16, 1883.

afterglow, with spectrum continuous in the green. I suspect that this was due to carbon dioxide from the pyrogallol solution. It was seen but once and could never be reproduced.

After chemically prepared nitrogen had been freed from the last traces of oxygen, I observed no afterglow in it when an ordinary induction current was used. After a condenser and spark gap had been introduced into the secondary circuit, however, a beautiful chamois-yellow mist filled the entire tube, and pulsated several centimeters into the connected tubes. On breaking the current, a bright afterglow lasted several seconds. At high pressures the thin white spark between the electrodes was surrounded by a sheath of this yellow, pulsating cloud.

Viewed through a pocket spectroscope of small dispersion, the spectrum consisted of three bright bands in the red, yellow (double), and green, and some weak lines in the red. The double yellow band was by far the brightest. Seen through a spectroscope of high dispersion, these four bands appeared weak and diffuse. The wave-lengths of their centers were approximately:

$$6240 \qquad \left\{\begin{matrix} 5780 \\ 5740 \end{matrix}\right. \qquad 5410$$

These bands seemed nearly or quite coincident with four bands of the nitrogen spectrum. At high pressures there were three maxima of the nitrogen spectrum in the region of these bands.

After the tube had been thoroughly desiccated with heated sodium, the afterglow vanished. It could not be obtained in nitrogen prepared from air.

This phenomenon seems likewise to depend on the presence of exceedingly small traces of water vapor or oxygen.

This afterglow seems to differ from those previously observed in the following respects: (1) It is produced only with condenser and spark gap; (2) it is seen only in nitrogen almost perfectly freed from oxygen; (3) the spectrum is banded, not continuous.

These experiments indicate not only that infinitesimal traces of a foreign substance can appreciably affect the spectrum of a

gas, but that these effects may be feebler, or altogether vanish when greater, but still small, quantities of the substance are present. Whether this action is the result of chemical activity or of disturbed electrical conditions, remains to be explained. One is reminded of the extraordinarily great influence of the presence of traces of moisture or oxygen on the cathode fall in nitrogen and hydrogen found by Warburg.[1] A direct connection between the two classes of phenomena is, however, difficult to trace. The effect of water vapor and oxygen on the spectrum of both hydrogen and nitrogen was to reduce the luminosity. The action of these substances on the cathode fall in hydrogen was opposite to its effect on that in nitrogen.

I take this occasion to thank Professor Warburg for his advice and help during this investigation.

BERLIN PHYSICAL INSTITUTE,
March 1900.

[1] WARBURG, *Wied. Ann.*, 31, 562, 566, 590, 1887.

THE EFFECT OF SOME IMPURITIES ON THE SPECTRA OF SOME GASES. II.

By PERCIVAL LEWIS.

I. HYDROGEN (*Continued*).

IN a previous paper[1] the effects of small quantities of mercury vapor and other substances on the spectrum of hydrogen were described. The discharge tubes used in those experiments were provided with external electrodes. In later experiments internal electrodes were employed, these being made of iron in order to prevent amalgamation with the mercury vapor. As previously, the hydrogen was generated electrolytically and freed from traces of oxygen by being passed through an alkaline solution of pyrogallol. Observations were made (1) with closed secondary current, (2) with Tesla current, and (3) with condenser and spark gap in the secondary circuit. The luminosity of *Ha*, of the green mercury line, and of that part of the compound hydrogen spectrum lying adjacent to the mercury line was measured at different pressures of the hydrogen and temperatures of the mercury reservoir from which the vapor was supplied. The results are given in the following tables:

I. WITH CLOSED SECONDARY CURRENT.

Temperature of mercury reservoir, 1°.

Hydrogen pressure	Intensity		
	Ha	Compound	*Hg*
0.6	120	11	17
1	76	6	13
1.2	81	7	15
1.4	76	5	6
3.2	65	4	4
5.8	36	5	2
9	20	8	4
13	5	5	1

[1] LEWIS, this JOURNAL, **10**, 137, 1899; *Wied. Ann.*, **69**, 398, 1899.

I. WITH CLOSED SECONDARY CURRENT.—*Continued.*

Temperature of mercury reservoir 18°.

Hydrogen pressure	Intensity		
	Hα	Compound	*Hg*
0.5	81	9	51
1.3	61	5	34
3.2	49	8	36
4.8	36	5	15
12	3	2.5	4

The reduction in luminosity due to the presence of mercury vapor is quite noticeable, although not so great as when external electrodes were used. With primary current kept constant, no maximum of intensity was reached down to pressures of 0.5 mm. With external electrodes such a maximum was found at a pressure of 3 mm.

The spectrum obtained with the Tesla current was quite feeble, and the photometric measurements in consequence relatively less accurate. The effect of mercury vapor was quite marked. A maximum luminosity of both the hydrogen and the mercury spectrum was reached at a pressure between 1 and 2 mm.

II. TESLA CURRENT.

Temperature of mercury reservoir 1°.

Hydrogen pressure	Intensity		
	Hα	Compound	*Hg*
0.6	4.5	0.7	2.3
1.3	5.3	2	3.
3.5	3.1	0.7	1.8
7	1.5	0.5	1.
19	0	0.5	Almost invisible
28	0	0.3	Almost invisible
Temperature of mercury reservoir 18°.			
0.5	1.5	0.7	4.6
0.7	1.5	0.7	4.6
1.2	3.1	2	7.4
2.4	2	2	11
5	0.8	0.7	2.4
12	0.6	0.7	1.3

With a condenser and spark gap the discharge was too irregular to permit consistent measurements to be made. The effect of the presence of mercury vapor seemed hardly noticeable.

II. NITROGEN.

The influence of small quantities of mercury vapor, water vapor, and oxygen on the spectrum of nitrogen was also studied. The discharge tube had external electrodes. The previously used voltometer was replaced by a gasometer filled with nitrogen generated chemically by heating a solution of ammonium sulphate and sodium nitrite. The arrangement of apparatus was in other respects essentially the same as that used in the earlier experiments on hydrogen. The gas was freed from oxygen by passing it through an alkaline solution of pyrogallol.

The first photometric measurements showed great irregularity in the intensity of the nitrogen spectrum, which invariably decreased considerably during the first few seconds after the current was closed. This irregularity disappeared after a time, although the conditions were never so steady as in the experiments with hydrogen.

INFLUENCE OF MERCURY VAPOR.

Experiments were made first with pure nitrogen, afterwards with mixtures of nitrogen and mercury vapor in varying proportions. The vapor pressure of the latter was regulated by cooling the mercury reservoir connected with the tube. The intensities of the brightest red and orange bands of the nitrogen spectrum, and that of the green mercury line, were measured at different pressures of the nitrogen, and at different temperatures of the mercury reservoir. The intensity of the adjacent region of the nitrogen spectrum was deducted from the apparent intensity of the mercury line to get the time intensity of the latter. With time, the intensity of the mercury line gradually diminished during continuance of the current, and was renewed after a few seconds break of the current. Possibly this was due to a partial removal of mercury vapor by the combination of nitrogen and mercury, as described by Threlfall.[1] The measurements given below were therefore made immediately after the current was closed.

[1] THRELFALL, *Phil. Mag.* (5), 35, 1, 1893.

PURE *N*.

Pressure of *N*	Red Band	Orange Band	Green *N*	*Hg*
0.8	57	—	6	—
1.5	70	36	8	—
1.8	87	49	24	—
2.5	87	57	39	—
3.2	100	—	—	—
3.5	105	65	36	—
4	100	61	31	—
5	93	57	—	—
5.5	87	53	—	—
6	81	45	31	—
6.5	75	42	28	—
9	61	39	24	—
10	53	39	28	—
17	39	26	18	—
25	33	20	16	—
60	16	9	8	—
100	8	—	—	—
Temperature of *Hg* Reservoir — 4°.				
1.5	45	—	22	20
2.5	49	—	28	14
4	81	—	26	13
5	70	—	26	13
Temperature of *Hg* Reservoir + 5°.				
0.9	9	11	5	26
1.3	28	22	8	25
1.7	45	—	15	27
2.5	57	36	16	26
3	70	—	18	24
4	70	45	22	23
7	61	42	28	17
13	49	31	26	7
26	33	—	—	2
Temperature of *Hg* Reservoir + 17°.				
1.5	23	—	9	33
1.9	31	26	16	37
2.5	53	26	24	29
3.5	65	31	20	33
3.8	65	33	24	29
4	61	31	28	25
6.5	61	33	28	21
9.5	45	21	18	15
15	36	28 (?)	16	8
26	31	16	13	3

The results for the red band are represented in the curves (Fig. 1). These curves show a maximum intensity at a pressure of about 3.5 mm. Above a pressure of some 20 mm the intensity decreases very slowly with increasing pressure.

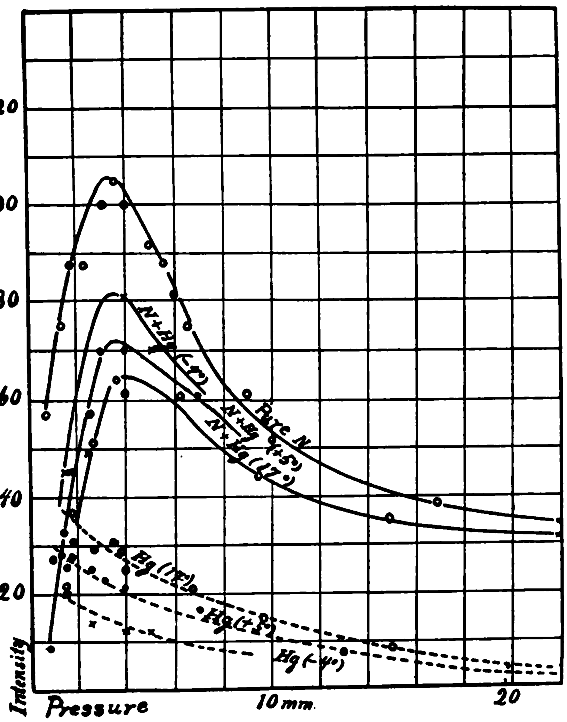


FIG. 1.

The intensity of these bands was considerably decreased by the presence of mercury vapor, although not so much so as in the case of hydrogen.

It is remarkable that the removal of mercury vapor from the tube, although followed by a diminution in the intensity of the green mercury line, was never followed by an increase in the intensity of the nitrogen spectrum. Such a result was invariably observed with hydrogen. Below is an example:

Pressure of N	Red	Orange	Green	Hg	
4 mm	107	42	33	0	No Hg
	45	28	18	52	Hg at 20°
	45	28	11	13	Hg at — 5°

INFLUENCE OF OXYGEN.

Oxygen was generated by heating potassium permanganate in a bulb, from which small quantities could be admitted into the vacuum tube. Measurements were made on pure nitrogen, or nitrogen containing 1 or 2 per cent. of oxygen, and nitrogen containing traces of oxygen; also on air and nitrogen containing 5 and 50 per cent. of air. These two series of experiments were made under different conditions with respect to current strength, etc.; therefore the results are not comparable.

The intensity of the brightest orange band was measured.

1. Pure N		2. $N+$ traces of O		3. $N+1$ or 2 per cent. O	
Pressure	Intensity	Pressure	Intensity	Pressure	Intensity
0.9	41	0.9	34	1.2	6
1.5	60	1.5	36	2.3	6.4
3	68	2.5	43	2.5	6.4
4	62	3.5	59	3	6
5	50	5	47	5	4.8
6.2	36	—	—	8	2
12	18	—	—		

4. $N+5$ per cent. air		5. $N+50$ per cent. air		6. air	
1.5	45	1.5	26	1	8
3.5	49	3	28	2.8	15
5	49	3.7	31	3.5	18
10	33	4.5	24	5.5	15
20	20	10	18	8	9

The results for oxygen are shown in Fig. 2. The curves for air are similar.

INFLUENCE OF WATER VAPOR.

The mercury reservoir was replaced by a bulb containing a very concentrated solution of sulphuric acid. After measurements of the intensity of the spectrum of pure nitrogen had been made,

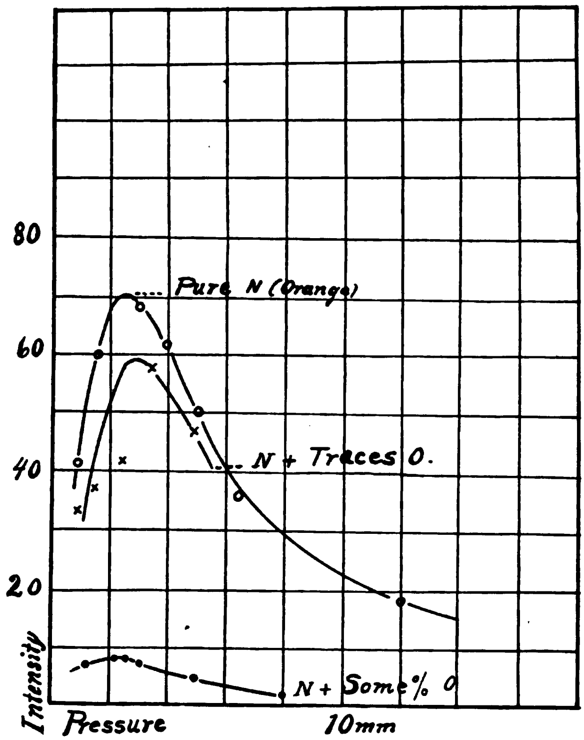


FIG. 2.

the cock between the bulb and the vacuum tube was opened. A considerable decrease (some 40 per cent.) in intensity was immediately observed. The results are given below.

1. Dry N			2. $N+$ traces of H_2O		
Pressure	Red band	Orange band	Pressure	Red band	Orange band
1.3	70	33	1.5	28	18
2	87	45	2.5	45	24
3	100	53	2.9	53	26
3.5	93	53	3.2	57	31
4.5	81	45	4	57	31
7.5	70	42	4.5	53	28
10.5	57	33	7.5	45	22
24	36	18	12	24	20

After further dilution of the acid, the effect was considerably greater.

Pressure	Red	Orange	
4	93	53	Dry N
	7	3	$N+H_2O$

The red, yellow, and green parts of the spectrum were almost destroyed in the presence of considerable traces of water vapor, while the blue and violet bands remained plainly visible. In pure dry nitrogen the discharge was light pink at low pressures, copper red at higher pressures. After addition of oxygen, the color became violet.

INFLUENCE OF SULPHUR AND IODINE VAPORS.

These substances were respectively sealed in the discharge tube and heated. No change in intensity of the nitrogen spectrum was apparently caused thereby.

BERLIN PHYSICAL INSTITUTE,
March 1900.

PROMINENCES OBSERVED AT KALOCSA ON MAY 28, 1900.

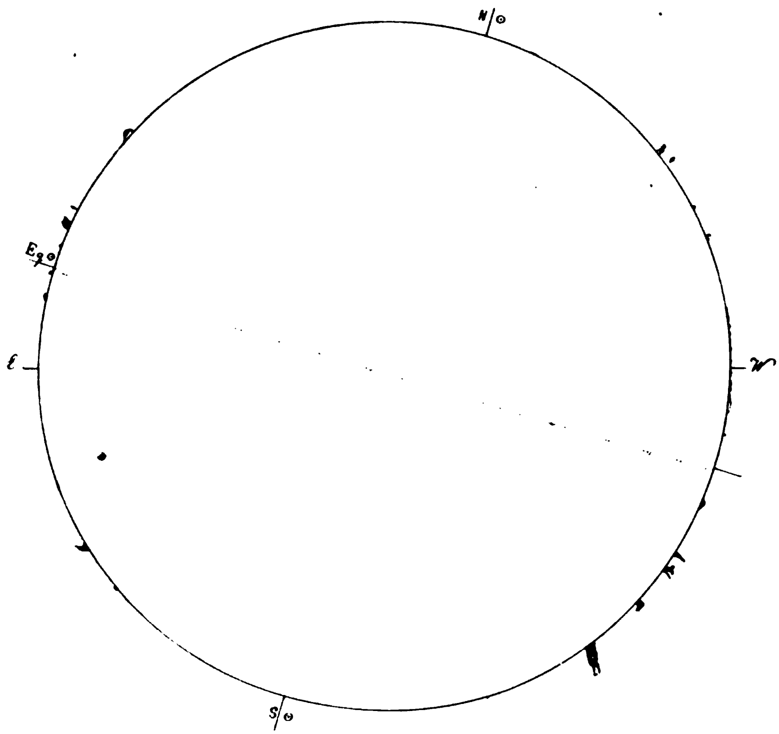
By J. FÉNYI, S.J.

An automatic spectroscope of six prisms was employed for the observations. The atmosphere was unfavorable, but it was nevertheless possible to secure a complete observation of the Sun's edge at the time when the eclipse was total in North America. The measurements are included in the following table, and the drawing (Plate II) represents the forms sketched at the eyepiece. The height of 102″ is unusual for the present epoch of minimum.

Gr. M. T. civil	Position from N through E	Heliographic latitude E	Heliographic latitude W	Height	Remarks
12^h 0^m	49°	+24°		24″	
12 52	307° 42′–308 22′		+55°	37	Changing rapidly
	306 46		+53	37	
	236 50 –237 36		–16	41	
1 17	233 50 –234 30		–19	33	Connected with last by light cloud
" "	226 56 –227 38		–26	28	
1 18	215 32 –217 24		–37	102	
1 24	119 30 –120 46	–47		32	Runs out into a very fine point
" "	64 22 – 65 46	+ 8		30	
1 30	63	+10		30	

Other smaller formations were observed in the positions 21°, 16°, 12°, 297°, 292°, 259°, 248°; from 265° to 280° the chromospheric flames were all inclined toward the equator.

PLATE II



PROMINENCES OBSERVED AT KALOCSA ON MAY 28, 1900

A SUGGESTED EXPLANATION OF THE SOLAR CORONA.

By J. SCHEINER.

IN addition to several bright lines the corona shows in the spectroscope a pretty intense continuous spectrum, in which the dark Fraunhofer lines have not yet been certainly detected and hence must be very weak. It follows from this that the corona can be due only in the slightest degree to reflected sunlight, and must be chiefly caused by the incandescence of solid or liquid particles.

The opinion seems hitherto to have been quite general that this incandescence arises in a manner similar to that of shooting-stars and meteors, from friction in the outer solar atmosphere which may be considered as constituted by the gases of the corona. This explanation does not seem to me to be valid, however, in view of the undoubtedly exceedingly slight density of the outer solar atmosphere. For how could such small particles come to incandescence from friction in a gas whose density is insufficient to appreciably affect by its resistance the orbits of comets passing through it? Moreover the particles would very soon fall into the Sun on account of the checking of the velocity, if they were not already wholly dissipated. New particles would therefore have to be constantly coming into the neighborhood of the Sun, and to render this view plausible, calculations have been made of the number of meteors striking the Sun on the basis of the corresponding figures for the Earth. I have elsewhere[1] pointed out the incorrectness of this procedure, since it involves the assumption that the universe is as densely occupied by meteoric matter as our solar system, which is without doubt not the case. Of course only a vanishingly small portion of the minute particles scattered through space, which have come into the domain of the Sun's attraction, has actually fallen into the

[1] *Strahlung und Temperatur der Sonne*, p. 66.

Sun; by far the greater part is forced into closed orbits by the Sun, and hence, in the course of the exceedingly long intervals of time in question, a sort of shell of meteoric particles has formed about the Sun, which shell must be inestimably more dense than space. This density is indeed applicable for our Earth, but only that of space for the Sun. We are here entirely leaving out of account the fact that perhaps the greater part of the meteors does not come from space, but originally belonged to the solar system.

The idea that the cause of the incandescence of the meteoric particles in the neighborhood of the Sun is to be found in the direct solar radiation is so obvious that it is surprising that it has not hitherto been expressed in the literature of the subject—at least I have been unable to find anything of the sort. This is perhaps because a rigorous solution of the problem of numerically determining the temperature of a body near the Sun is impossible, even if we were oriented as to its chemical constitution. But by adopting certain simplifying premises it is nevertheless possible to make a determination of temperature which must at least be of the right order, and which will therefore settle the question whether solid or liquid particles at distances from the Sun within the extent of the corona can be brought to the temperature of incandescence as a result of the solar radiation alone.

The premises are as follows: (1) The body is very small so that it will reach a stationary condition in a very short time, and the temperature of the interior will not appreciably differ from that of the surface. This assumption is nearly fulfilled by meteoric particles. (2) The emissive and absorptive power is independent of the temperature. This condition is the more nearly fulfilled as the body more closely approaches the absolutely black body; and it is for such a body only, which does not occur in nature, that the temperature can be exactly determined. After the analogy of the determination of temperature in case of the Sun, this may be designated as the effective temperature.

If we denote by q the quantity of heat radiated by an element of surface of the Sun in a unit of time, and by ϕ the apparent semidiameter of the Sun, the integral of the radiation upon an element of area perpendicular to the line of sight will be

$$W = \pi q \sin^2 \phi \, .$$

Hence the quantities of radiation received at various distances from the Sun vary with the square of the sine of the Sun's apparent semidiameter. According to the most recent researches, the quantity of radiation received per minute on a square centimeter at the distance of the Earth is $W = 4.0$ gram-calories.[1] Here $\phi = 16'$. An element of surface at such a distance that the Sun's semidiameter would subtend an angle of $45°$—or at a distance of something less than half the solar radius from the Sun's surface, therefore corresponding to about the limit of the average extension of the corona—would therefore receive 23083 times as much radiation, or 92332 gram-calories.

On the given assumptions the effective temperature of the surface element can be computed from this, since a stationary condition will ensue as soon as the quantity of heat received and absorbed in a unit of time equals that emitted.

From Stefan's law this will occur at the absolute temperature T as soon as

$$W = \sigma \, . \, T^4 \, .$$

The constant σ has been repeatedly determined in recent years, most lately and probably most accurately by Kurlbaum,[2] who obtained $\sigma = 1.28 \times 10^{-12}$, with the second as the unit of time. Hence $T = 5890°$ for the above defined point at the edge of the corona; that is, an absolutely black unit of surface would assume this as a stationary temperature, in so far as it was perpendicular to the line to the Sun's center. If we substitute for the unit of surface a small sphere under otherwise unchanged physical conditions, the receiving surface will be one fourth as large as the radiating surface in comparison with the plane surface element, and for this the mean value per second will be

[1] *L. c.*, p. 36. [2] *Wied. Ann.*, **65**, 746, 1898.

$W = 385$ gram-calories. Hence we obtain $4160°$ for the effective temperature of a small absolutely black body.

In view of the high degree of certainty as to the numerical values of W and σ, this value must be regarded as quite reliable; but if we attempt to pass from this over to the true temperature we shall be at once confronted with the difficulties already indicated.

All variations of the physical constants will produce a diminution of the value of T, but they cannot be exactly computed, because on leaving the absolutely black body the dependence of the absorptive and emissive power upon the temperature, which has not yet been sufficiently investigated, enters into the problem. A temperature of $4000°$ is therefore to be designated as the upper limit. The lower limit is at present beyond any exact computation; possibly we should come somewhere near it if it were permissible to use data of radiation applicable to the Earth. But unfortunately Stefan's law cannot be applied to bodies of such complicated physical structure as planets surrounded by atmospheres. The following figures may, however, give us some idea of the matter.

At the distance of the Earth from the Sun the absolute temperature of the small absolutely black body would be stationary at $338°$; but the mean stationary temperature of the Earth's surface is $288°$, and it should be noted that Zenker's researches indicate that the stationary temperature of the Earth's surface without solar radiation lies at $200°$, when there will be equilibrium between the outward radiation and the conduction from the Earth's interior, so that the effect of the solar radiation amounts to only $88°$.

Should we desire to deduce from this the stationary temperature of the Earth's surface, at the edge of the corona, according to Stefan's law, after we had computed, in place of the constant σ, a constant s, not physically definable, to be 278×10^{-10}, we should get $T = 1530°$, which is decidedly smaller than the upper limit but nevertheless considerably above the temperature of incandescence. I would again

expressly state, however, that there is no physical justification for this computation.

From the above considerations there seems to me to be no occasion for seeking any other cause for the continuous spectrum of the corona than in the very simple explanation given above

ASTROPHYSICAL OBSERVATORY,
Potsdam.

REMARKS ON THE CONSTRUCTION AND ADJUSTMENT OF SPECTROGRAPHS. II.[1]

By J. HARTMANN.

III. SIZE OF PRISMS NECESSARY.

THE most favorable kind of prisms having been determined above, it remains to decide upon the most suitable size of those for a given instrument. Although it appears almost a matter of course that the prisms should always be large enough to receive the whole of the beam coming from the collimator, I shall nevertheless show that a certain, if only slight, increase in the brightness of the spectrum can be attained with somewhat smaller prisms. It seems desirable to determine accurately the minimum size of prisms possible, since the difficulty of accurate figuring and of perfect equilibrium of temperature during the measures increases with the size of the prisms, as does their price, and particularly their weight, as well as that of the whole prism box.

If the prisms are attached in the usual way, with their triangular surfaces between two metallic plates, it is obvious that their height, *i. e.*, the length of the refracted edge, must be made a few millimeters greater than the diameter of the collimator objective, and thin sheets of some not too hard, poorly conducting material, such as ivory, asbestos paper, etc., should be placed between the prisms and the metal plates. In this way we may avoid the passage of the rays through parts of the glass which are less homogeneous than the rest of the prism, either on account of unequal pressure of the plates or on account of the effect on the temperature of contact with the metal.

The side S of a prism which can receive the whole of the light coming from a collimator objective of diameter $2r$ may be computed from the formula

$$S = \frac{2r}{\cos i},$$

[1] Translated from the *Zeitschrift für Instrumentenkunde*, Vol. XX, Nos. 1 and 2, 1900, to which acknowledgment is also due for illustrations reproduced in this article.

where i is the angle of incidence at the surface of the first prism. If we now withdraw the prism from the position $A\,B\,C$ (Fig. 3), in which it receives the whole beam in the direction of its base $A\,C$, to about the position $A'B'C'$, the light coming from the segment $E\,F\,G$ of the objective (shown in the figure as turned ninety degrees from its actual position) passes by the refracting edge B' unutilized, but all the remaining light now has to cover a shorter distance in the glass than before by the thickness of the glass plate between $B\,C$ and $B'\,C'$. In this way we obtain enough diminution of loss by absorption so that up to a certain limit an increase in the brightness of the spectrum is possible by means of thus withdrawing the prism. The prisms may then be reduced in size by the portion $A\,A'\,C'D$, and the size of the prism box and also of the camera objective are correspondingly decreased.

Let $I\,K$ be a chord of the circular aperture of the collimator parallel to the refracting edge, g be its distance from the center of the aperture, reckoned as positive toward the refracting edge, $h = I\,K$ its length, and $2a$ the corresponding angles at the center. Then

$$g = -r \cos a\,, \quad \text{and } h = 2r \sin a\,.$$

If a second chord is drawn at a distance of $g + dg$ from the center, the two chords will include an element of surface of the aperture of area

$$dv = hdg = 2r^2 \sin^2 a da\,.$$

If the chord $E\,F$, which separates the rays entering the prism from those which pass by the refracting edge, is at a distance of g_0 from the center of the aperture, and has the angle $2a_0$ at its center, we shall have, similarly,

$$g_0 = -r \cos a_0\,.$$

The pencil passing through the element of surface dv strikes the prism at a distance of

$$k = (g_0 - g) \sec i$$

from the refracting edge, and has to traverse in the prism a path of length

$$w = 2k \sin \frac{b}{2} = 2\,(g_0 - g) \sec i \sin \frac{b}{2}\,.$$

For m prisms the length of path in the glass is mw.

If for brevity we set

$$2mr \sec i \sin \frac{b}{2} = z\,,$$

we get

$$mw = 2mr\,(\cos a - \cos a_0) \sec i \sin \frac{b}{2} = z\,(\cos a - \cos a_0)\,.$$

The coefficient of absorption of the glass being c, as before, the intensity of the light emerging from the prisms, after traversing the distance mw in the glass, is given by

$$J = J_0\, c^{mw} = J_0\, c^{z\,(\cos a - \cos a_0)}\,.$$

The light passing through the surface element dv accordingly becomes

$$dL = J_0\, c^{mw}\, dv = 2r^2 J_0\, c^{z\,(\cos a - \cos a_0)} \sin^2 a da\,,$$

and the total quantity of light transmitted through the whole prism train is

$$L = 2r^2 J_0 \int_0^{a_0} c^{z\,(\cos a - \cos a_0)} \sin^2 a da\,.$$

Now the light emerging from the collimator objective is

$$L_0 = r^2 \pi J_0\,,$$

and consequently the weakening of the light by the prisms is

$$\frac{L}{L_0} = \frac{2}{\pi} \int_0^{a_0} c^{z\,(\cos a - \cos a_0)} \sin^2 a da\,.$$

Loss of light by reflection is disregarded in this whole discussion, since it is independent of the size of the glass surfaces.

The integration is rendered easily possible by development in series. If we further let $c = e^x$, whence $x = \log \text{nat}\, c$, we get

$$\frac{L}{L_0} = \frac{2}{\pi} e^{-xz \cos a_0} \int_0^{a_0} e^{xz \cos a} \sin^2 a da\,.$$

Now

$$\int e^{xz\cos\alpha}\sin^2\alpha d\alpha=\int(1-\cos^2\alpha)\left(1+\frac{xz\cos\alpha}{1!}+\frac{x^2z^2\cos^2\alpha}{2!}+\frac{x^3z^3\cos^3\alpha}{3!}\right.$$

$$\left.+\ldots\right)d\alpha=\int\left\{1+xz\cos\alpha+\left(\frac{x^2z^2}{2!}-1\right)\cos^2\alpha+\left(\frac{x^3z^3}{3!}-\frac{xz}{1!}\right)\cos^3\alpha\right.$$

$$\left.+\left(\frac{x^4z^4}{4!}-\frac{x^2z^2}{2!}\right)\cos^4\alpha\ldots\right\}d\alpha\,.$$

Introducing the known values of the integrals of the cosine powers, we obtain the series

$$\int e^{xz\cos\alpha}\sin^2\alpha d\alpha=\frac{1}{2}p_0\alpha+\frac{2}{3}p_1\sin\alpha+q_1\sin\alpha\cos\alpha+q_2\sin\alpha\cos^2\alpha$$
$$+q_3\sin\alpha\cos^3\alpha+\ldots.$$

where the coefficients p and q have the following values, the symbolic designation $(n)=\frac{x^nz^n}{n!}$ being employed:

$$p_0=1+\frac{1}{4}(2)+\frac{1}{6}\cdot\frac{3}{4}(4)+\frac{1}{8}\cdot\frac{3}{4}\cdot\frac{5}{6}(6)+\frac{1}{10}\cdot\frac{3}{4}\cdot\frac{5}{6}\cdot\frac{7}{8}(8)+\ldots..$$

$$p_1=\frac{1}{2}(1)+\frac{1}{5}(3)+\frac{1}{7}\cdot\frac{4}{5}(5)+\frac{1}{9}\cdot\frac{4}{5}\cdot\frac{6}{7}(7)+\frac{1}{11}\cdot\frac{4}{5}\cdot\frac{6}{7}\cdot\frac{8}{9}(9)+\ldots.$$

$$q_1=\frac{1}{2}p_0-1$$

$$q_2=\frac{1}{3}p_1-\frac{1}{2}(1)$$

$$q_3=\frac{1}{3}[2q_1+1-(2)]$$

$$q_4=\frac{1}{4}[3q_2+(1)-(3)]$$

$$q_5=\frac{1}{5}[4q_3+(2)-(4)]\,.$$

Since the above integral vanishes for $\alpha=0$, we obtain for the weakening of the light by the prism the expression

$$\frac{L}{L_0}=\frac{2}{\pi}e^{-xz\cos\alpha_0}\sin\alpha_0\left\{\frac{1}{2}p_0\frac{\alpha_0}{\sin\alpha_0}+\frac{2}{3}p_1+q_1\cos\alpha_0+q_2\cos^2\alpha_0\right.$$
$$\left.+q_3\cos^3\alpha_0+\ldots\right\}.$$

The constants of spectrograph III, which has been described above, are

$$2r = 32\text{mm}\ , \quad b = 63^\circ 28'.0\ , \quad i = 61^\circ 43'.5, \quad m = 3\ .$$

From this follows

$$\log z = 2.02772\ .$$

For the flint glass of these prisms

$$\log c = 9.9972428\ ,$$

whence

$$x = -\ 0.0063488$$

and

$$\log xz = 9.83042\text{n}\ .$$

For this spectrograph the expression for $\frac{L}{L_0}$ accordingly takes the form

$$\frac{L}{L_0} = 0.63662\, e^{0.67674 \cos \alpha_0} \sin \alpha_0 \Big\{ 0.529175 \frac{\alpha_0}{\sin \alpha_0} - 0.232558$$
$$- 0.470825 \cos \alpha_0 + 0.22209 \cos^2 \alpha_0 - 0.05688 \cos^3 \alpha_0 + 0.01029 \cos^4 \alpha_0$$
$$- 0.00145 \cos^5 \alpha_0 + 0.00017 \cos^6 \alpha_0 - 0.00002 \cos^7 \alpha_0 \Big\}\ .$$

The series converges so strongly as to offer no difficulties in calculation. Thus I obtained the following table:

α_0	$\frac{L}{L_0}$	Brightness of spectrum
180°	0.5379	1.0000
170	0.5424	1.0083
160	0.5514	1.0250
150	0.5591	1.0393
140	0.5603	1.0416
130	0.5512	1.0247
120	0.5290	0.9834
110	0.4926	0.9158
100	0.4425	0.8227

If the prism is withdrawn in the manner described there occurs, at first, a not inappreciable increase in the brightness of the spectrum, reaching 4 per cent. at 140°. In spectrograph III the prisms would have a length of face of 67.55 mm in order to receive all the light from the collimator, while the prisms with the greatest light power according to the above table have a

length of face of only 59.65 at 140°. A face of 60 mm was accordingly given to the first prism, that nearest to the collimator objective. In the second prism this was increased to 65 mm on account of the spreading of the beam from the dispersion, and in the third prism the length of face was 70 mm.

It is by no means intended in what has been said that use should be made in all cases of this reduction in the size of the prism, but it is solely desired to determine the limit permissible for such a reduction. It would be entirely incorrect to place a prism in the path of the rays in such a way that its smallest portion, in the neighborhood of the refracting edge, should be unused. On account of its intensity this part furnishes the most valuable contribution to the spectrum, and care must therefore be taken that the surfaces of the prisms are perfectly figured close up to the refracting edge.

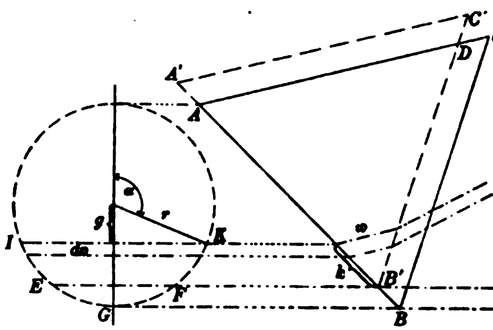


Fig. 3.

We may here mention an objection which might be offered to this reduction in the size of the prisms. It is well known that for the same kind of glass and the same refracting angle the resolving power of a prism is proportional to the length of face. This theorem, however, is rigorously true only for beams of rectangular section which fill out the whole prism; in the case before us, where the larger prisms have the single advantage that they could also include the light coming from the small segment *EFG* (Fig. 3), that proportionality does not occur. According to the researches of Rayleigh a circular beam of diameter $2r$ has in the spectroscope the same resolving power as a rectangular beam of width $1.8\,r$. Now, since in the suggested reduction of the prisms the section of the beam

approaches more nearly the rectangular form, the smaller prisms will be at least equally effective as the larger ones in respect to resolving power.

IV. TESTS AND ADJUSTMENT OF APPARATUS.

The first tests of the new spectrographs which I undertook dealt with their separate optical parts. The prisms were investigated with a large Bamberg spectrometer, and the lenses were tested on an optical bench.

The preliminary tests of the lenses had given the focal lengths for the different colors (particularly for $H\gamma$ light, by photographs of a hydrogen tube), and so the slit could be accurately placed in the photographic focus of the collimator. As the accurate focusing of the collimator is very important I will here describe the process I have employed for determining the focus for $H\gamma$.

The collimator objective to be investigated was placed upon an optical bench with a Geissler hydrogen tube set up several meters distant. The objective was covered with the diaphragm containing two slits parallel to each other, each of 2 mm width and 16 mm distant from each other. When the direction of these slits is parallel to the Geissler tube, two plane beams of light emerge from the objective, which intersect in a straight line which is the image of the tube projected by the lens. If we therefore receive the rays on a photographic plate we shall obtain a *single* image of the tube, that is a straight line, only in case the plate passes exactly through the intersection of the beams, or is precisely focused. But if the plate is not placed at exactly the right position, being at a greater or less distance from the objective, it will give two images of the tube, that is, two parallel straight lines, the separation of which, e, is proportional to the distance of the plate from the position of the image projected by the objective. If the displacement of the plate in the direction of the axis of the objective is measured on a scale which reads A for the correct setting on the image of the tube, and if we obtain two images on the plate separated from each

other by the distance e when the scale reading is A, we shall get the general relation

$$\frac{e}{A-A_0}=\text{const} .$$

If we make two exposures of this sort with different focusing, we shall obtain the relation

$$\frac{e_1}{A_1-A_0}=\frac{e_2}{A_2-A_0},$$

whence follow these two expressions for determining A_0:

$$A_0=A_1-e_1\frac{A_1-A_2}{e_1-e_2},$$

$$A_0=A_2-e_2\frac{A_1-A_2}{e_1-e_2}.$$

It will be of advantage to arrange the exposures so that the true position of the image is included between them, that is, so that $A_1<A_0$ and $A_2>A_0$; in which case e_1 must receive the minus and e_2 the plus sign. Where great accuracy is desirable several exposures at different settings of the plate will be made, instead of only two.

The procedure described is exceedingly reliable. In the ordinary method of focusing, in which we judge only by the *sharpness* of the image, the determination of focus is often uncertain by whole millimeters for lenses of small angular aperture, but a few extra-focal exposures, as above, will give the tenth of a millimeter with absolute certainty. I will give here a series of such exposures made with the collimator objective of spectrograph III, as an illustration. I obtained the following eight exposures on the same plate when the distance of the Geissler tube from the front edge of the cell of the objective was D = 3028.4 mm :

No.	A	e
1	189 mm	+ 2.053 mm
2	179	+ 1.779
3	169	+ 1.480
4	159	+ 1.197
5	109	— 0.244
6	99	— 0.536
7	89	— 0.822
8	79	— 1.112

On combining the exposures in pairs 1 and 5, 2 and 6, 3 and 7, 4 and 8, there result these eight values A_0:

$$\begin{array}{r} A_0 = 117.49\,\mathrm{mm} \\ 117.53 \\ 117.56 \\ 117.53 \\ 117.50 \\ 117.52 \\ 117.57 \\ 117.53 \\ \hline \text{Mean, } 117.53\,\mathrm{mm.} \end{array}$$

The distance of the plate from the edge of the cell of the objective corresponding to the value $A=0$ is 458.78 mm, whence the distance of the image from that edge is $d=576.31$. The value of d was determined in this way for a number of different values of D, and thus the position of the focus for parallel rays, that is for $D=\infty$, was computed in the ordinary manner. In order to discover any change of focus with temperature, I made the measurements at two different temperatures, and obtained for the distance d of the focus from the edge mentioned

$$\begin{array}{ll} \text{at } 19^\circ\!.2\ \mathrm{C}, & d_0 = 486.17\ \mathrm{mm} \\ \quad 2.0 & \quad 486.35 \end{array}$$

Although the difference of these two numbers lies near the limit of accurate determinations, in view of the accuracy of the method employed it may be considered trustworthy; whence would follow a shortening of the focus relative to brass of 0.1 mm for a change in temperature of 10° C. Since the distance of the slit of the collimator objective in spectrograph III is fixed once for all, the rays will emerge from the collimator exactly parallel only at a definite temperature t_0. At a temperature of $t_0-10°$ they emerge with a divergence equal to that from a slit at a distance of 2.3 km. It is clear that so slight a divergence of the rays has no effect on the sharpness of the spectrum if the small alteration of the path of the ray due to the temperature coefficient of the collimator is compensated by suitable focusing of the camera.

The following procedure may be adopted for obtaining a sharp image over the longest possible region of spectrum. If the collimator objective is achromatized in such a way that the point of inflection of the color curve falls at that wave-length for which the prisms are to be set at minimum deviation, we shall not place the slit exactly in the focus for this wave-length, as this has the shortest focus of any point in the whole spectrum, but we shall slightly increase the distance of the slit from the collimator objective. Then two sets of rays lying on either side in the spectrum will emerge from the collimator in exact parallelism, hence homocentrically, while the middle part of the spectrum will be also homocentrically represented for the reason that the prisms are set at the minimum of deviation for this point. It has been possible in case of the two spectrographs under discussion to secure sharp definition of a much longer extent of spectrum than with any previous stellar spectrographs. In apparatus I, which has one prism, the region between Fraunhofer lines D and N, corresponding to a difference of wave-length of $230 \mu\mu$, is sharply defined; with spectrograph III, having three prisms, the region from *b* to K is depicted with perfect sharpness. It is of great importance, for stellar spectrographs in particular, to extend the region of sharply defined spectrum as far as possible, as we then obtain a considerably more extensive supply of observed data with the same exposure time as if a short portion only of the spectrum was well defined by the spectrograph.

After completing the further adjustment of the apparatus—the accurate perpendicularity of the edges of the prisms to the axes of collimator and camera, the setting of the prisms at the minimum of deviation for $H\gamma$, and the determination of the most suitable inclination of the plate-holder to the axis of the camera—an exhaustive testing of the completed spectrograph was undertaken.

The essential condition placed on the optical performance of a spectrograph is briefly that it shall unite in an absolutely sharp image of the slit on the photographic plate all the rays of the same wave-length which fall upon the collimator objective after

passing through the slit, neglecting the hardly appreciable diffraction phenomena which depend upon the aperture of the camera objective. This image is the "line" corresponding to that wave-length. The condition of sharp definition point by point, according to which a sharp point image on the plate corresponds to each separate point of the slit, is not absolutely essential, and in concave gratings this condition is not fulfilled. A good prism train, however, will satisfy this condition also. If a spectrograph conforms to the condition first named, it is at once evident that the position and the sharpness of the line cannot be at all affected by the question whether the ray has fallen perpendicularly or obliquely upon the slit, or whether the ray has been concentrated accurately on the slit by a lens or upon a point in front of or behind it. If any such alteration in the path of the rays produces displacement, broadening, or lack of sharpness of the line, then the above fundamental principle of the apparatus is not fulfilled, and such an instrument is not suitable for exact measurements. Conclusions as to the actual appearance of the lines in the spectrum, as to their sharpness, breadth, and diffuseness on one side, and similar matters, cannot be drawn until the observer has convinced himself that the cause of these phenomena cannot lie in the instrument employed.

Photographs of suitable spectra are obtained in the preliminary tests of the spectrograph. Direct sunlight is less to be recommended for this purpose; for if it is allowed to fall upon the slit, after reflection from the mirror of a heliostat, only a narrow beam of light will enter the collimator, if the slit is not very narrow, so that only small portions of the prisms and objectives are employed, while the remaining parts contribute nothing to the production of the image. Even if the solar spectrum photographed in this way is perfectly sharp, it proves nothing as to the excellence of the instrument. The most important rule in all test plates is always to uniformly illuminate the *whole* collimator objective. This can be accomplished in case of sunlight by the use of a projecting lens, or much more simply and certainly by placing a ground glass disk at a slight distance in front of the

slit. Diffuse light of the sky may also be used for test plates. If a solar spectrum obtained in this way appears perfectly sharp it may be assumed that the spectrograph has no large errors, but such a test is not entirely certain, as the numerous lines and weak contrasts of the solar spectrum easily allow a slight lack of sharpness in the lines to escape attention.

The line spectra of metals and of gases in Geissler tubes are decidedly better adapted for testing the apparatus. Any one having an electric arc lamp at his disposal can form an accurate opinion as to the quality of the spectrograph in a few minutes. The lamp should be placed some 50 cm in front of the slit and a ground glass disk inserted between the lamp and the slit. One may be quite certain that the apparatus is excellent, if on vaporizing a metal, as iron, in the arc, the lines remain absolutely sharp with strong illumination, particularly if they are not diffuse on one side. In default of an arc lamp the spark spectrum of metals can be employed, but much longer exposures will be necessary on account of its weaker luminosity. The desired result will be obtained more rapidly in this case if a projecting lens is substituted for the ground glass disk for giving full illumination to the collimator objective. To secure certainty that the lens correctly performs its purpose the eye should be placed in the position of the image of some readily visible lines, the plate-holder having been removed from the camera. For this purpose the bright lines of the air spectrum in the yellowish-green, which always occur in spark spectra, are suitable. On looking toward the camera objective the *whole* collimator objective should be seen as uniformly luminous in the proper color through it and the prisms. Geissler tubes giving strong line spectra, as hydrogen tubes, are also very useful. The capillary part of the tube should be placed parallel to the slit and as close to it as possible, attention being given that the slit is narrower than the luminous capillary and receives light uniformly over its whole width. This may be recognized by the fact that the edges of the slit only, and not a part of the tube, are perceived as boundaries of the lines when examined with an eyepiece put in the

position of the plate-holder and sharply focused on the lines. If the eyepiece is then removed, the *whole* of the collimator objective must again be uniformly luminous in the proper color. In these tests longer exposures should be always employed along with the shorter ones, and one should convince himself whether the lines remain perfectly sharp in all cases.

In the investigation of the two spectrographs often alluded to, I have employed another method, which is indeed much more troublesome, but furnishes an absolutely certain criterion as to the trustworthiness of the apparatus. It will always be necessary to fall back upon this method if the lines have lacked sharpness in the above-mentioned tests, and the cause is to be further investigated.

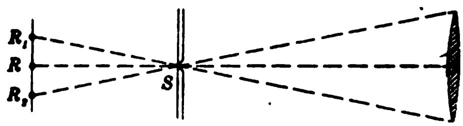


Fig. 4.

A hydrogen tube R was mounted parallel to the slit S at a distance of about 25 cm from it (see Fig. 4) in such a way that it could be moved micrometrically in a direction perpendicular to the axis of the collimator. For this purpose I mounted it on the slide of a dividing engine. A narrow, plane beam of light will enter the collimator if the slit is not too narrow (say, from 0.05 mm to 0.1 mm). In one position of the tube R_1, this beam will fall upon one edge of the collimator ohjective, and at another position R_2, upon the opposite edge of the collimator objective. The light from the tube will pass from the point R, lying between R_1 and R_2, accurately through the axis of the collimator and through the center of the prisms and the camera objective. Let the whole distance R_1 R_2 be divided into a number of equal divisions so that the light may be successively thrown from the different points upon all points of the collimator objective. Let the tube be now set on one of the divisions, the middle of the slit be covered by a small strip, and a spectrum be photographed. After interrupting the current the tube is moved into the position R, the middle of the slit is opened and the lateral portions are closed, and a second exposure is made on

the same plate, the plate-holder having of course remained untouched meanwhile. In this way two spectra are obtained on the plate one above the other, the inner of which has been produced by the central portion of the spectrograph, while the exterior spectrum lying on both sides is due to light which has passed through the outside parts of the objectives and of the prisms. If the exterior spectrum then shows no displacements of the line with respect to the interior one, it follows that the central and the lateral beams intersect precisely in the plane of the plate. But if the two spectra are displaced with respect to each other it will always be possible to cause this displacement to disappear by focusing the plate. This problem may be seen to be entirely identical with the method of focusing explained above. Having accomplished the result that the central ray intersects a lateral ray exactly in the plane of the plate, the spectra of all the separate lateral rays should then be successively photographed at the same focus, the Geissler tube being set at the different divisions of the space R_1 R_2. For comparison the spectrum produced by the axial rays from R should be introduced in every spectrum. If all of the spectra thus obtained are then tested under the microscope, and if no one of them exhibits a displacement from the central spectrum, then the condition proposed above is rigidly fulfilled, the spectroscope is free from aberrations, and the position and sharpness of the lines is independent of the direction from which the rays fall upon the slit.

Two cases may arise if a perfect coincidence with the central spectrum has not occurred for all the lateral spectra. Either a uniform progress will show itself in the displacement, so that the spectrum produced, say from R_1, is displaced most strongly in the direction of shorter wave-lengths, and that from R_2, on the contrary, in the direction of longer wave-lengths as compared with the central spectrum. This would prove that the plate was not correctly focused as it should have been, and a progressive change of this sort can always be overcome by changing the position of the plate. But if the two spectra from R_1 and R_2 are displaced in the *same* direction with respect to the central

spectrum, the apparatus is without question imperfect and can only be employed by stopping out a part of the prism. The following figures, which I have found in investigating spectrograph I, which has only *one* prism, may serve as an illustration of this. The measurement of seven spectra obtained in the manner described yielded the following displacements with respect to the central spectrum:

Point	Displacement
1 (R_1)	+0.040 mm
2	+0.014
3	0.000
4 (R)	0.000
5	+0.003
6	+0.020
7 (R_2)	+0.050

Since all the displacements have the same sign, all lying in the direction of shorter wave-lengths, there will be no focus at which all the rays can be united in a sharp image on the plate. If we are willing to permit a lack of sharpness of 0.1 mm, the lateral portions of the prisms from 1 to about 2.3 and from 5.5 to 7 will have to be covered. As a third of all the light would be lost in this process, however, a new prism was obtained for the spectrograph, which on renewed investigation showed itself to be entirely free from error.

If the lines of the separate lateral spectra should appear diffuse instead of sharp on the plates, the prism or perhaps one of the objectives is imperfect in the direction of the refracting edge. The path of the rays in this direction must then be separated into sections by diaphragms placed over the collimator objective, and each must be investigated for itself. For the investigation described above, such diaphragms can also be employed, their aperture consisting of a slot parallel to the refracting edge;[1] but the danger arises of putting an injurious pressure on the parts of the apparatus in changing the diaphragms, which might affect the accurate coincidence of the

[1] Cornu suggested the employment of a diaphragm with circular aperture of about 5 mm diameter (*Spectre normal du Soleil*, p. 10).

spectra. This danger is avoided by the use of the movable Geissler tube.

I have been able to prove in the way described that all the rays which pass in any way through the optical parts of spectrographs I and III are perfectly united in a sharp image of the slit. As may be seen from what precedes, such a union of the rays on the plate is only possible when the latter is perfectly focused, and all spectral plates therefore require an extremely careful focusing. The means hitherto employed of concluding as to the correct position of the plate solely from the sharpness of the lines of the spectrum appear to me to be insufficient, and an attachment has therefore been applied to the two instruments which permits the use of the method of focusing by extra-focal exposures described above. The arrangement consists in placing two diaphragms successively in front of the objective of the collimator, with which we first allow the light to fall only upon the portion of the prisms near the refracting edge, and then only upon the portion near the base of the prisms, the light meanwhile being prevented from falling upon the opened plateholder. The plate being out of the correct focus, the two spectra obtained through the diaphragms are placed in juxtaposition by covering up part of the slit.[1] The correct focus is then obtained as described with the greatest precision from the displacement of the two spectra. The two apertures may be made in one and the same diaphragm, but in that case the observer is restricted to the employment of spectra with few lines, such as that of hydrogen, while when separate diaphragms are employed the focusing can be effected with daylight.

I must not omit to mention that the method of focusing here described is only permissible after the optical parts have been investigated as above and found satisfactory, for it is only in this

[1] NEWALL also suggested (*M. N.*, 57, 572, 1897) a similar method of employing diaphragms in focusing, but in finding the focus he availed himself only of the fact that at that point the images from the two apertures in the diaphragms coincided. Similar methods have been known for a long time: H. Schroeder gives a very useful procedure in his *Photographische Optik*, p. 171. The advantage of the method of extra-focal exposures that I have employed consists in the fact that a reliable linear measurement is substituted for the always uncertain estimate of the sharpness or coincidence of lines.

case that we are justified in regarding the point of intersection of the two emerging beams from the objective as the focus of the rays coming from the *whole* objective.

This method of extra-focal exposures has also proved to be of especial utility in testing and in exactly determining the focus of telescope objectives at this Observatory. I will here only briefly mention the following point: With the use of suitable diaphragms the extra-focal exposures will furnish the focal length of all the separate portions of the objective, and hence accurate numerical data as to the course of the zonal errors and of the astigmatism. If the extra-focal images are received upon the slit of a spectrograph, and not directly on the photographic plate, the color curve of the objective may be obtained at the same time. The results of researches of this sort carried out here on larger objectives will be published in detail elsewhere.

V. A DIAPHRAGM FOR THE SLIT OF THE STELLAR SPECTROGRAPH.

In photographing stellar spectra for the determination of motion in the line of sight it is necessary to place the spectrum of a terrestrial source beside that of a star, and for the sake of accuracy in measurements, the comparison spectrum is placed as near as possible above and below the star spectrum. The following device was attached to spectrograph III for accurately placing the spectra in juxtaposition, and it has proved very useful in the work that has been done in the laboratory.

A slide of sheet brass, which can be moved back and forth something more than 2 cm in the direction perpendicular to the slit, is attached just in front of the slit. This slide contains an aperture of the form shown in Fig. 5. The central part of the aperture is a rectangle $ABCD$, somewhat greater than the height of the slit and wide enough so that the slit can be reached for cleaning. An isosceles triangle EFG joins the aperture at the left and makes it possible to give any desired breadth from about 3 mm down to less than 0.1 mm to a spectrum produced at the middle of the slit. A rectangle $HIKL$ connects with the side BC on the right, and into this projects the tongue MNO similar to the triangle EFG. A portion of the middle of the slit up to

3 mm length can be covered by this tongue, while the slit remains free for receiving the comparison spectrum above and below it. In the measurement of the spectra it is convenient to have the comparison spectra only a few tenths of a millimeter broad, similar to the star spectrum, and not of indefinite breadth. For effecting this, a second and smaller slide (Fig. 6) was attached to the first, containing only a triangular aperture PQR, as nearly as possible like the tongue MNO, by which it is partially covered in use as may be seen from Fig. 6. The upper slide may be moved a few millimeters on the lower one in the direction perpendicular to the slit, and is held in position by friction with the

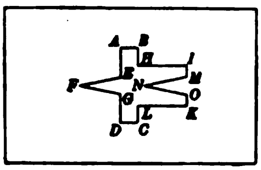


Fig. 5.

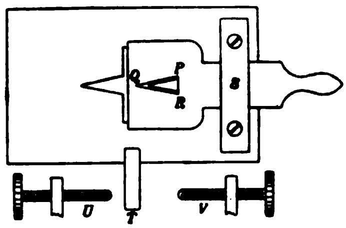


Fig. 6.

clip S. The comparison spectra will have a greater or less breadth as the upper slide is placed more or less toward the left upon the lower slide.

The motion of the whole diaphragm is limited by the adjustable stops U and V, against which the projection T, which also serves as a handle, strikes. These stops make it possible to always bring exactly the same parts of the diaphragm in front of the slit, so that the same breadth can be given to all the spectra on a series of plates. This diaphragm is capable of very numerous applications. Spectra may be taken with a width of 15 mm (AD), 8 mm (HL), and 3 mm down to less than 0.1 mm (EFG). Two comparison spectra of any desired width can be then placed beside the last named spectra, of less than 3 mm width, either in direct contact or symmetrically separated by a space. It is easy with this device to place three spectra in exact juxtaposition in a space one half a millimeter wide.

ASTROPHYSICAL OBSERVATORY,
Potsdam.

NOTE ON THE SPECTRUM OF SILICON.

By FRANZ EXNER and EDUARD HASCHEK.

IN an article "On the Origin of Certain Unknown Lines in the Spectra of the Stars of the *β Crucis* Type and on the Spectrum of Silicon," by Mr. Joseph Lunt, which appeared in No. 4, Vol. XI, of this JOURNAL, attention was called to Dr. Gill's recognition in the spectra of several stars of lines of the wave-lengths 4552.79, 4567.09, and 4574.68, the identity of which had not previously been determined. McClean had observed the same lines in the spectrum of *β Crucis*, assigning them wave-lengths 4552.6, 4567.5, and 4574.5. Sir Norman Lockyer had also recorded these lines as unknown. Mr. Joseph Lunt has, however, made a series of experiments which show with a high degree of probability that these lines belong to the spectrum of silicon, and has expressed his regret that the measurements accessible to him, those of Hartley and Adeney, as well as those of Eder and Valenta, do not include this special region of the spectrum, and so do not permit a direct confirmation of his view concerning the origin of the lines in question.

As we undertook some time since[1] the measurement of lines in the spectrum of the spark between electrodes of metallic silicon, with the aid of a large Rowland concave grating, and as the data from our table of wave-lengths completely confirm the opinion of Mr. Lunt as to the origin of the lines in question, we believe the communication of these results in the following table, so far as we have made measurements in the region of the Sun's spectrum, will not be regarded as superfluous.

[1] *Sitzungsberichte der Wiener Akademie*, Bd. 108, 1899.

SILICON.

λ	i	λ	i
2987.77	1	3905.71	5
3086.6	1[1]	4021.0	1[1]
3093.6	1[1]	4030.1	2[1]
3591.0	1[2]	4096.8	1[1]
3791.8	1[1]	4103.2	1[2]
3796.50	2[2]	4103.7	1[2]
3806.90	3[2]	4128.1	5[1]
3853.62	1[2]	4131.0	6[1]
3854.02	1[2]	4552.75	3[2,3]
3856.19	5[2]	4567.95	1[2]
3862.80	4[2]	4574.9	1[2]
3883.46	1	4764.20	1

In the recorded intensities *i*, 1 stands for the weakest lines.

From this table it appears that the lines observed by Dr. Gill and by McClean undoubtedly belong to the spectrum of silicon. The pronounced discrepancy in the wave-length of the line 4567.09 may arise through an error. The two lines 3834.4 and 3826.7 attributed to silicon by Eder and Valenta, the existence of which in the spectrum of silicon was doubted by Mr. Lunt and which are lacking in our table, are iron lines. The line 3807, which Mr. Lunt suspected was a silicon line, although lacking in the silicon lines recorded by Eder and Valenta, appears in our table at 3806.90. In view of the above agreement it can scarcely be doubted that the opinion of Mr. Lunt was correct. The fact that the silicon appears in the spectra of so large a number of stars seems to us to be of especial interest because in our experience in this part of the spectrum we have found it very difficult to establish the presence of silicon as an impurity.

VIENNA, May 13, 1900.

[1] Very diffuse. [2] Diffuse. [3] The neighboring air line is 4552.65.

PRESSURE IN THE SPARK.

By EDUARD HASCHEK and HEINRICH MACHE.

IN Vol. X, No. 3 of the ASTROPHYSICAL JOURNAL Dr. J. F. Mohler computed the pressure of the electric spark from observations on the displacement of spectral lines. These measurements he undertook in the belief that the considerable pressures in the electric spark observed by the present writers would necessitate a marked displacement of the spectral lines. From the fact that under the experimental conditions of his investigation the observed displacement of the lines was relatively small he concluded that the pressures found by us were too high. Dr. Mohler found further that the influence of the surrounding gas upon the pressure of the spark affirmed by the present writers did not exist. In reply we wish to call attention to the following considerations.

Our statements concerning the pressure in the spark were accompanied by a detailed description of the apparatus and the conditions of experimentation. By comparing the values obtained with the transformer and those obtained with the Ruhmkorf coil the great influence of the apparatus used upon the results is apparent. The reason for this difference can in the opinion of the writers be sought only in the difference in the quantity of energy represented in single sparks in the two cases. That it depends upon this consideration is apparent from the interdependence between the capacity applied and the observed pressure, which was confirmed by Dr. Mohler also. This difference is especially noticeable when the energy of the spark is changed to the extent involved in passing from the transformer to an induction coil. In our experiments with the transformer an alternating current of from 6 to 9.5 amperes and 100 volts was driven through the primary. In the induction coil, on the contrary, a steady current of about 10 amperes and 12 volts

was used. The difference in energy consumption was thus very considerable, as was also the observed spark pressure. Thus Dr. Mohler, working with an induction coil, obtained values which agree with ours obtained in a similar way, at least so far as the strong influence exercised by the materials of the electrodes admits of a comparison between his results and our own. Further, in the statements of Dr. Mohler concerning the influence of the surrounding gas the present writers are able to see only a confirmation of their own results. We of course do not maintain, however, that numbers which differ by 45 per cent. are equal. That the pressure is higher in illuminating gas than in air may be due to the fact, as maintained by Dr. Mohler and which seems obvious to us also, that carbon may have been deposited from the gas upon the electrodes and that the present writers measured, not the pressure for brass, but for carbon. For carbon the observed spark pressure is indeed materially higher, and blackened electrodes give larger values than bright ones. Now for carbon dioxide, with which Dr. Mohler repeated the experiment, it is possible that like conditions entered. Dr. Mohler finds the relation between the pressure in carbon dioxide and air to be 1.45, while the ratio found by the present writers was 3. If one considers the quantitative difference in the energy consumption in both cases, it is easy to conclude that here also carbon was separated and deposited upon the electrodes, and indeed in greater quantities in using the transformer than in the case of the induction coil, whereby the observed discrepancy may be explained.

Minor Contributions and Notes

A NEW STAR IN *AQUILA*.

From an examination of the Draper Memorial photographs, Mrs. Fleming has discovered a new star in the constellation *Aquila*. Its position for 1900 is R. A. $= 19^h\ 15^m\ 16^s$; Dec. $= -0^\circ\ 19'.2$. It was too faint to be photographed on 96 plates taken between August 21, 1886, and November 1, 1898, although stars as faint as the thirteenth magnitude are visible on some of them. It appears on 18 photographs taken between April 21, 1899, and October 27, 1899. On April 21 it was of the seventh magnitude, and on October 27, 1899, of the tenth magnitude. Two photographs taken on July 7, and July 9, 1900, show that the star is still visible, and that its photographic magnitude is about 11.5. A photograph taken on July 3, 1899, shows that its spectrum resembled those of other new stars, while a photograph taken on October 27, 1899, shows that the spectrum resembled those of gaseous nebulæ.

On July 9, 1900, the object was observed with the 15-inch equatorial by Professor Wendell, who estimated its magnitude at 11.5 to 12.0, and confirmed the monochromatic character of its spectrum.

E. C. Pickering.

THE YERKES OBSERVATORY OF THE UNIVERSITY OF CHICACO.

BULLETIN NO. 13.

VARIABLE STAR OBSERVATIONS WITH THE 12-INCH AND 40-INCH REFRACTORS.

The principal observations of variable stars hitherto made at the Yerkes Observatory were included in Professor Barnard's study of star clusters with the 40-inch telescope. In connection with his extensive triangulations of certain clusters, he has observed the variations in brightness of a number of variable stars discovered photographically at the Arequipa station of the Harvard College Observatory. Professor Barnard has also made miscellaneous observations of variable

stars in the course of his general micrometrical work with this instrument.

During the summer of 1898 Mr. J. A. Parkhurst, whose private observatory is at Marengo, Illinois, was given the use of the 12-inch refractor on certain nights of each week for variable star observations.

The work with the 12-inch has recently been supplemented by observations with the 40-inch refractor, whose great light-gathering power has made it possible to follow a number of variables through very faint minima. This preliminary report will be followed by more definitive results when the magnitudes of the comparison stars have been determined with the stellar photometer, now in use in this work. The magnitudes given in the present paper are only approximate, based on the assumption that the limit of the 12-inch is 14.0 magnitude, and that of the 40-inch 17.0 magnitude.

Of the 22 stars in this report, 16 are contained in Chandler's *Third Catalogue of Variable Stars* and supplements. For these stars Table I gives from this catalogue the minimum magnitude and number of minima on record, to show what was previously known on the subject; also the results of the work at the Yerkes Observatory from January to June 1900, giving the date and magnitude of the observed minima.

TABLE I.

	From III. Cat.		Yerkes observations	
	Min. mag.	No.	1900	Min. mag.
267 *V Andromedae*	——	—	January	14
2530 *V Canis minoris*	<13.7	—	April	15
2625 *V Geminorum*	12.0–14.0	3		
2815 *U Geminorum*	13.1	—		
2976 *V Cancri*	<12	3	February	12
4315 *R Comae*	<13.5	—	March	<14
5070 *Z Virginis*	<14	—	May	15
5430 *T Librae*	<14.7	3	Feb. or Mar.	<16
5593 *W Librae*	<14	—		
5830 *R Scorpii*	<13	—	May	16
5831 *S Scorpii*	<13	—		
6100 *RV Herculis*	——	—	February	<15
6871 *V Lyrae*	<12	—		
6894 *S Lyrae*	12.0	—	May	16
7458 *V Delphini*	12 ?	—		

Six of the stars in Table I did not pass minimum during the time covered by this report; the following notes show the observed magnitudes, the stars being referred to by their numbers only:

2625 14.5 magnitude by the end of January, brighter by middle of February.

2815 Carefully followed throughout its period. About 14 magnitude at normal light, but with considerable fluctuations.

2976 Has a 13 magnitude companion, 10ˢ.8 preceding, on the parallel.

5593 15 magnitude and rising early in February.

5831 Apparently stationary at 15 magnitude in February.

6871 About 15.5 magnitude early in June and still fading.

7458 Maximum 1899 October 1, at 7.5 magnitude; invisible in 40-inch (low power) 1900 July 20, therefore < 17 magnitude: a range of nearly or quite 10 magnitudes.

TABLE II.

STARS NOT IN CHANDLER'S THIRD CATALOGUE.

	1900		Discoverer	*Ast. Nach.*	
	R. A.	Dec.		Vol.	Page
(1922)	$5^h\ 20^m\ 8^s.6$	$+36°\ 48'\ 53''$	Ceraski	148	15
(4696)	13 2 39 .5	−12 37 50	Schwassmann	152	183
(6458)	17 56 17 .2	+54 52 45	Anderson	151	307
(7258)	20 11 32 .9	+30 46 3	Anderson	150	325
(7579)	21 3 38 .5	+82 39 50	Ceraski	147	142
(8517)	23 39 41 .1	+56 1 35	Anderson	148	79

Particular attention has been paid to new variables, not in the Third Catalogue, whose light-curves suggest very faint minima. Table II gives six stars selected from these, showing the number (in parenthesis, provisionally assigned by Mr. Parkhurst), the place for 1900, found by micrometer measures with the 40-inch, except for the 2d and 5th, the discoverer, and a reference to the announcement of discovery in the *Astronomische Nachrichten*.

The preliminary results of the observations of these new variables are given in the following notes:

(1922) Minimum early in March, about 15 magnitude.

(4696) Not visible in the 12-inch June 20, limit about 13 magnitude. Between 13 and 14 magnitude July 5, with 40-inch.

(6458) Not visible in 12-inch in March, limit 14 magnitude; had risen to 10 magnitude by June 23.

(7258) Minimum in May, about 14.5 magnitude.

(7579) Had passed below the limit of the 40-inch in June, and therefore not brighter than 17 magnitude.

(8517) Stationary at about 15 magnitude in January, rising in February.

GEORGE E. HALE.

July 6. 1900.

POSITIONS OF *EROS* (433) IN 1893, 1894, AND 1896.[1]

APPROXIMATE positions of *Eros* (433) during the oppositions of 1894 and 1896 will be found in *Circulars* Nos. 36 and 37. Since then the photographs from which these positions were derived have been measured by the method described in the Harvard *Annals*, Vol. XXVI, p. 237, and reduced by the method of Turner. The measurements have been made by Miss E. F. Leland and the reductions by Miss A. Winlock aided by Miss I. E. Woods. These photographs were taken with the Bruce, Bache, and Draper photographic doublets, whose apertures are 60, 20, and 20 cm, and the focal lengths such that 1 mm equals 60″, 179″, and 163″, respectively. Photographs taken with these instruments are designated by the letters A, B, and I, respectively. The smaller instruments photograph a field 10° square, and as some of the images fall near the corners of the plate it was not supposed that positions could be determined from them with a high degree of accuracy. In some cases the images are more than 5° from the center of the plates, and are consequently much distorted, the greatest diameter exceeding a minute of arc; yet, as will be seen below, the accuracy of the places does not greatly differ from that ordinarily obtained with meridian circles. The most remarkable conclusion to be derived from these observations is that if, in the future, any other object like *Eros* should be discovered, we have at this Observatory the means of tracing its path since 1890, during the time in which it was moderately bright, with nearly as great accuracy as if a series of observations had been taken of it with a meridian circle.

In the following table the designation of the original negative is given in the first column. The date, the Greenwich Mean Time of the middle of the exposure, and the duration of the exposure, are given in the next three columns. Two enlargements, on a scale of 0.1 cm. = 10″, were made from each of these negatives, and their designations are given in the fifth column. The number of catalogue stars on these enlargements used to determine the constants of the plates, such as errors of scale, orientation, etc., is given in the sixth column. The standard coördinates of *Eros* are given in the seventh and eighth columns, and the resulting right ascension and declination for 1875 in the ninth and tenth columns. The two measures of each plate are independent, except for errors in the original negatives and in the

[1] *Harvard College Observatory Circular* No. 51.

POSITIONS OF *EROS.*

Plate	Date	G.M.T.	Exp.	Enl.	St.	X	Y	R. A. 1875	Dec. 1875	Δ R. A.	Δ D.
	y m d	h m	m			″	″	h m s	° ′ ″	s	″
I 9801	1893 10 28	21 55	14	6441	9	− 9627.2	−15941.0	5 58 48.11	+53 39 46.8	+0.03	−0.1
				6442	9	− 9626.9	−15941.2	5 58 48.14	+53 39 46.7		
I 9832	1893 10 30	20 18	10	6377	9	+ 9760.3	−14440.0	6 4 33.13	+54 6 25.8	+0.03	−1.3
				6378	9	+ 9760.7	−14441.3	6 4 33.16	+54 6 24.5		
I 9862	1893 10 31	21 21	15	6391	7	−10903.8	+ 3653.4	6 7 37.42	+54 20 11.2	+0.40	+2.2
				6392	7	−10900.1	+ 3655.3	6 7 37.82	+54 20 13.4		
I 10095	1893 11 26	20 26	17	6390	7	−15368.2	+ 4066.2	7 17 31.35	+57 49 34.0	−0.29	−1.0
				6389	7	−15370.6	+ 4065.5	7 17 31.06	+57 49 33.0		
I 10215	1893 12 19	18 21	14	6375	4	+10544.4	+ 5340.3	7 45 56.41	+54 38 39.2	+0.28	+0.1
				6376	4	+10546.8	+ 5340.5	7 45 56.69	+54 38 39.3		
I 10280	1893 12 23	19 49	13	6416	4	−10591.8	− 642.9	7 45 57.59	+52 58 16.4	−0.19	−1.7
				6417	4	−10593.7	− 644.5	7 45 57.40	+52 58 14.7		
I 10321	1893 12 27	17 32	10	6383	7	+10580.3	+10362.3	7 44 43.17	+50 55 0.2	+0.03	−0.6
				6382	7	+10580.7	+10361.7	7 44 43.20	+50 54 59.6		
I 10469	1894 1 19	16 57	10	6408	7	− 654.1	−15761.6	7 26 28.40	+28 45 48.4	−0.20	+0.9
				6409	7	− 656.7	−15760.7	7 26 28.20	+28 45 49.3		
I 10559	1894 1 25	16 16	13	6393	9	− 3564.4	+11541.9	7 23 33.46	+21 14 58.0	−0.01	−1.0
				6394	9	− 3564.6	+11541.0	7 23 33.45	+21 14 57.0		
A 222	1894 2 5	15 26	60	6410	7	− 4630.1	+ 5011.8	7 23 17.83	+ 8 45 22.8	−0.05	+1.9
				6411	7	− 4630.8	+ 5013.7	7 23 17.78	+ 8 45 24.7		
A 246	1894 2 16	14 49	12	6414	8	+ 1059.4	− 9589.6	7 29 58.55	− 0 21 42.7	−0.08	+0.6
				6415	8	+ 1058.2	− 9589.0	7 29 58.47	− 0 21 42.1		
I 10685	1894 2 16	14 59	13	6436	11	+10997.4	−13093.8	7 29 59.01	− 0 21 54.4	−0.32	−3.6
				6437	11	+10992.6	−13097.4	7 29 58.69	− 0 21 58.0		
B 10909	1894 4 16	14 13	10	6371	7	+ 2201.3	+13823.8	9 17 0.62	−13 33 54.0	−0.03	+1.8
				6374	7	+ 2200.9	+13825.6	9 17 0.59	−13 33 52.2		
B 10951	1894 4 18	14 29	10	6365	9	+ 8489.9	+12761.3	9 21 47.01	−13 38 52.7	−0.10	+1.3
				6370	9	+ 8488.5	+12762.6	9 21 46.91	−13 38 51.4		
B 11174	1894 5 19	14 16	10	6344	7	+ 7170.1	−10985.5	10 38 1.88	−14 57 21.9	+0.10	+3.6
				6346	7	+ 7171.6	−10981.9	10 38 1.98	−14 57 18.3		
B 15531	1896 4 6	20 52	60	6360	7	− 7958.9	− 3771.5	18 36 59.92	−38 32 48.8	+0.03	+1.0
				6361	7	− 7958.6	− 3770.5	18 36 59.95	−38 32 47.8		
B 16108	1896 6 4	16 40	70	6350	5	−10686.4	− 9103.3	18 30 6.81	−40 2 45.2	+0.75	+0.2
				6351	5	−10677.8	− 9102.7	18 30 7.56	−40 2 45.0		
B 16157	1896 6 5	19 54	10	6355	5	+15242.6	+ 8861.3	18 27 51.27	−39 58 33.0	+0.24	+0.7
				6357	5	+15245.4	+ 8861.9	18 27 51.51	−39 58 32.3		
B 16165	1896 6 5	22 4	11	6353	4	+ 1306.6	− 8891.1	18 27 39.55	−39 58 2.1	+0.07	+3.4
				6354	4	+ 1307.4	− 8887.7	18 27 39.62	−39 57 58.7		
B 16518	1896 6 29	19 17	15	6348	9	− 9732.7	+ 4124.9	17 37 43.91	−36 21 26.7	−0.09	+1.4
				6349	9	− 9733.9	+ 4126.3	17 37 43.82	−36 21 25.3		
A 1876	1896 6 30	13 46	60	6413	6	+ 5864.8	+ 4719.0	17 36 22.23	−36 11 20.9	0.00	+0.5
				6412	6	+ 5864.8	+ 4719.4	17 36 22.23	−36 11 20.4		

method of reduction. The differences in the two results for the right ascension, and for the declination, are given in the last two columns.

On I 9832 the image is irregular. The position of the brightest part is given. The center precedes it $0^s.66$, and is $8''.6$ south. On A 222 and A 1876 the images are much elongated, owing to the motion of *Eros*. The means of the measures of the ends are given. The discordance in the positions derived from I 10685 and B 16108 is probably due to the poor quality of the images.

A complete discussion of these measures, including the original settings and the results for each comparison star, is in course of preparation for the *Annals*. The positions of the stars have been taken from the Catalogues of the *Astronomische Gesellschaft*, except in the

case of the plates taken in 1896 for which the Cordoba Catalogues have been used. The average value of the 296 residuals for the catalogue stars is, for x, $\pm 1\overset{'}{.}03$, for y, $\pm 1\overset{'}{.}06$. The average difference of the standard coördinates of the two positions of *Eros* is, for x, $\pm 1\overset{'}{.}8$, for y, $\pm 1\overset{'}{.}4$. For the three Bruce plates these values become $\pm 0\overset{'}{.}6$ and $\pm 1\overset{'}{.}0$, respectively.

EDWARD C. PICKERING.

June 7, 1900.

Eclipse Reports

PRELIMINARY RESULTS OF THE UNITED STATES NAVAL OBSERVATORY ECLIPSE EXPEDITIONS.

In equipping two stations on the central line, one in North Carolina and one in Georgia, the intention was merely to duplicate the work so as to avoid the danger of cloudy weather. The spectroscopic work of the Georgia station was transferred to a station near Griffin at Experiment, for the purpose of getting near the northern limit of totality to secure as long an exposure as possible on the reversing layer. With the exception of the spectroscopic instruments of the Georgia station, which were at Griffin, the work at the two stations was generally the same.

The general plan of observations at all three stations included a determination of the longitude by exchange of signals with Washington, and the latitude by Talcott's method. This was specially important in the station near the northern limit, as the maps of that region were unreliable, and some time was spent in locating the station, so as to be about three miles from the northern limit. This part of the program was carried out at all three stations, and the results will soon be ready for publication.

The photographic work at both central stations included photographs of the corona with the 5-inch photoheliograph lenses of 40 feet focal length, and with several smaller instruments, some of which were provided with color screens for the purpose of securing photographs of the corona from the light in the green region of the spectrum, and also for testing at the same time their value in cutting down the sky glare in long exposures.

The photographic program was not carried out in accordance with the plans as originally formed, but was modified to make the work on the two stations fill in what was thought at that time to be deficiencies in the work of other eclipse parties. For this reason it was thought advisable to obtain at each station a photograph of long exposure with the long focus lens. The photographs obtained with

each instrument consist of exposures of 2, 5, 10, 35, 45, and 2 seconds, 9 plates altogether. The plates used were Seed's double coated 14×17, backed with a thick coat of artists' lampblack.

While the 2 seconds exposures are too long to show the extreme inner corona and the prominences satisfactorily, they are of value in connection with 5 and 10-second exposures in giving on a large scale the details of the inner and middle corona. Of the two long exposures, that of 45 seconds at Pinehurst caught the first rays of returning sunlight, but both give fine details of the outer corona to a distance of one diameter of the Moon. The last of the Barnesville plates, exposure 2 seconds, also caught the returning sunlight, but shows the prominences and inner corona, close up to the crescent of the photosphere.

Two 6-inch Dallmeyer lenses of 36 inches focus, one of them provided with a color screen containing a solution of picrate of copper, were used at Pinehurst, and the color screen was placed outside of the outer lens. Three photographs were obtained with these of 2, 5 and 40 seconds exposure. On the same polar axis with these two was a short focus Voigtländer lens of 4 inches aperture and 8 inches focal length, with which two pictures were taken; one, with a color screen, of 20 seconds, and the other, without a color screen, of 40 seconds. The placing of the color screen in front of the objective seems to have caused in both of these instruments reflections and distortions of the image to such an extent as to seriously interfere with good definition. All of the four plates of long exposures are rather dark, and show relatively but little extension of the corona, not beyond three diameters.

At Barnesville the five instruments were arranged on the same polar axis; two were provided with color screens similar to those at Pinehurst, with the exception that the color screens were placed inside of the lenses, and the results are very much more favorable. With the 6-inch visual lens of 102 inches focus, the color screen was placed about 18 inches in front of the photographic plate; with the other instrument, a Dallmeyer lens 3.5 inches aperture and 9.5 inches focal length, the color screen was placed just inside the inner lens of the system. With the former of these two instruments was used a 6-inch Brashear photographic lens of 90 inches focus, belonging to Mr. C. A. Post, of New York; and as a companion to the small Dallmeyer lens a similar instrument of 4 inches aperture and 17 inches focal length was used

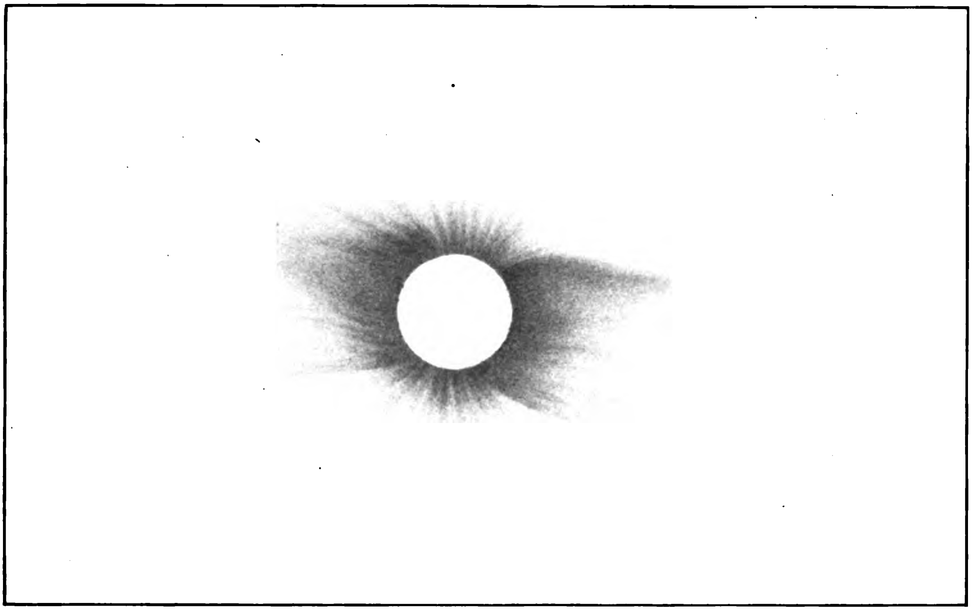
without a color screen. There was further on this axis a 6-inch Dallmeyer lens of 33 inches focus. The exposures with all of these instruments were 2, 5, 5, and 40 seconds, the last one concluding just at the end of totality. This was not intentional, as the long exposure was to have come in the middle of the eclipse, but owing to the time required for the vibration of the axis, caused by changing the plates, to cease, it was found necessary to carry out the program of exposures as given above. The photographs with the 6-inch visual lens, color screen, are very sharp and show a considerable extension of the corona, which apparently differ in no wise from the one taken with the companion instrument except in showing a greater extent of corona. The long exposures, however, show the advantage of the color screen in cutting out the sky glare, thus giving a greater extension of the faint coronal streamers. There also seems to be a greater extent shown of the polar streamers relative to equatorial portions than in photographs taken without the color screen. With the long exposure on the Dallmeyer instrument, however, provided with a color screen, the extension of the corona can be distinctly traced on the west beyond *Mercury*, which is farther, so far as I can learn, than has been obtained elsewhere at this eclipse either photographically or visually. In the companion picture on the 4-inch Dallmeyer lens, the development could not be carried nearly so far on account of the fogging of the plate due to sky glare. Taking all the results together, it seems to me that the experiments with the color screen have yielded sufficient material to warrant its further use at coming eclipses. With the experience gained concerning the position of the screen and the material with which to fill it, there ought to be obtained a greater extension of the corona with the color screen than without it. (Plate III, from drawing.)

SPECTROSCOPIC RESULTS.

In arranging the general plan of observations to be made by the Observatory eclipse expeditions, the spectroscopic work was considered of the highest importance, as the work on the reversing layer is independent of the duration of totality, and an eclipse of such brief duration as the last one has even an advantage over one of long duration for observations of this character.

The instruments employed consisted of a prismatic camera at Pinehurst, a slitless spectrograph at Barnesville, in the line of prismatic spectroscopes; two grating objectives, consisting of a plane grating in

PLATE III



THE CORONA

DRAWN FROM PHOTOGRAPHS BY L. E. JEWELL

combination with a quartz lens, and three concave gratings using slits and quartz lenses for forming the image on the slit plate.

Of these instruments the first of the concave gratings was used by Dr. Ames at Pinehurst with a slit two or three millimeters wide and about one millimeter long. The expedient of using a wide slit was adopted after the instrument had been erected at Pinehurst, on account of the evident difficulty which would be met in bringing and keeping the image of the reversing layer upon the slit. The quartz lens used with this grating, however, was 3 inches in diameter and about 35 inches focal length, from which it is evident that only about one third of the light from the reversing layer would be received by the grating.

The second concave grating was used by Dr. Crew at Griffin with a narrow slit about .05 of a millimeter, and a quartz lens 72 inches focus and $3\frac{7}{16}$ inches aperture.

The third concave grating, one of 21 feet radius, used by Dr. Humphreys of the University of Virginia, also at Griffin, was used in the same manner with a narrow slit.

With none of these concave gratings were any results of value obtained. This, in two of them, is unquestionably due to the fact that the image of the reversing layer was not on the slit during the exposure, while in the case of Dr. Ames at Pinehurst the failure was due, first, to the cause already mentioned concerning the short focal length of the quartz lens, combined with the shortness of the exposure which could be obtained on the reversing layer at a station near the central line of totality. While the failure to obtain results with these gratings is disappointing, it does not preclude their use to great advantage at subsequent eclipses, as a mounting has already been devised which obviates the use of the slit.

The plane grating at Griffin in charge of Mr. Jewell also failed to get any results, but this was due entirely to an unfortunate accident, and in no way reflects upon the capacity of the instrument to give all that was expected of it.

The results with the remaining grating objective, in charge of Dr. Huff at Pinehurst, are sufficiently valuable to show the great advantage of the use of the grating, either plane or concave, in future spectroscopic eclipse work. With this instrument three photographs were obtained: (1) the flash spectrum of the second contact of only 1 second exposure; (2) 25 to 30 seconds later on the corona with an

exposure of only 5 or 6 seconds; (3) Fraunhofer spectrum after the third contact, exposure 1 second.

The plate-holders in all the grating spectroscopes were shaped to the focal curve of the spectrum, and it was expected that all parts of the spectrum would be in sharp focus, but on trial at the eclipse stations it was found that the plates furnished would not bend the required amount, and thus only a limited portion of the spectrum is in sharp focus.

Plate IV shows an enlarged positive on glass of the flash spectrum obtained at the second contact, exposure 1 second, at Pinehurst, N. C. Dimensions of the grating are as follows:

Six-inch flat grating, ruled space 3.5×5 inches, 15,000 lines to the inch. Extremely bright in the first order on one side, and in the second order on the opposite. The spectrum is almost entirely free from diffused light.

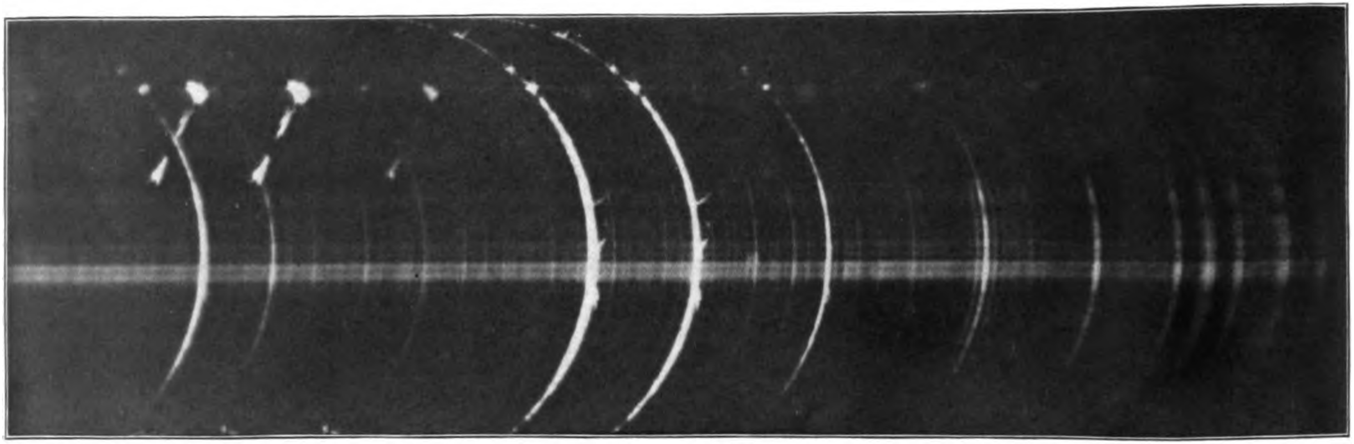
The original photograph extends from wave-length 3000 to 6000, giving a dispersion of about 10 inches. Some of the important facts which may be drawn from a brief inspection of this portion of the spectrum are worthy of attention.

The prominences, as shown in the light of the H and K lines, show details which compare favorably with large scale photographs, and which are rather better than in small scale photographs. The plate shows marked differences in the prominences as given by the lines of helium and hydrogen and those by the calcium lines H and K. The bright horn-like prominences shown in H and K, as well as one entirely detached, are not shown at all in the helium and hydrogen lines. Some of the prominences are shown in the bright strontium line 4078, just above $H\delta$. This is also the case with the titanium lines.

Three of the carbon bands at $\lambda 3883$ show very brilliantly up to a height of 100 to 200 miles, and faintly up to a height of 200 to 400.

Notwithstanding the short exposure of 1 second, considerable detail is shown in the green coronal line 5303, and in the violet coronal line at 3987. The distribution of material producing these two lines is shown to be entirely different, and to have no connection whatever with the prominences, and little, if any, with the material giving the continuous spectrum of the corona. The distribution of material in 3987 is more like that of the matter in the chromosphere than in 5303.

PLATE IV



SPECTRUM OF THE SECOND FLASH

PHOTOGRAPHED WITH AN OBJECTIVE GRATING BY W. B. HUFF

A faint though very remarkable line at 3965, which seems to be strongest at an elevation of from 1000 to 4000 miles, and very weak in lower strata, is scarcely visible in the spectrum of the base of the chromosphere. This has been identified as one of the lines of the "principal series" of *Parhelium* and several lines in Professor Lord's flash spectra, which share the same peculiarity of distribution of light, also are identified as belonging to the same element, but not all to the same series.

The plate shows 20 lines between H and K, and if it had been in focus throughout its length, would evidently have contained about 1500 lines.

In the second plate taken, the coronal lines are well shown, and four new ones have been found in the ultra-violet at approximately 3381, 3456, 3643, and 3801. The line at 3381 is remarkably strong, and indicates a distribution of material similar to that shown by the green coronal line at 5303; while the other three show a similarity in distribution to that in the violet at 3987.

The separating power of this apparatus is well shown by the fact that in the original negative the hydrogen and calcium components of H are distinctly separated.

The plates showing the third contact were spoiled by continuing the exposure after the Sun came out.

On the fourth plate, of the Fraunhofer spectrum, the strong lines are shown bright at the edges of the spectrum, and a displacement is noticeable between the dark and bright portions similar to that shown in Professor Campbell's pictures taken at the 1898 Indian eclipse. The photograph shows definitely that this displacement is due to the fact that the source of the dark and bright lines is different, and is purely an angular displacement, the dark Fraunhofer lines being produced by the photosphere, and the bright lines by the base of the chromosphere at considerable elevation above this. The aluminium and titanium lines also show both the dark lines and the bright extensions, in addition to helium, hydrogen and strontium, though in none of these is there indicated more than a very slight displacement of the dark and bright portions.

The prismatic camera.—This consisted of a 60° prism of 6 inches length and faces 5 inches broad, used in connection with a 4-inch visual lens of 60 inches focus. The plates used were 5×7 Erythro, very obligingly sent on a short time before the eclipse by Mr. Douglass.

Although the definition of the plate is not good, due to the curvature of the focal plane, the results are worthy of careful study, as it shows lines between C and K at least 350 to 400 in number, including 6 or 8 between D_3 and C. The exposure on this plate was made at the second contact, and is estimated to have been less than one second, and yet the C line comes out very distinct, bright and extensive. On the second plate, with an exposure of 40 seconds, the clock worked badly, and the lines are somewhat drawn out. There are shown, however, as dark lines, the various groups of lines due to the Earth's atmosphere, including α, B, a, A, and traces of atmospheric lines hear D.

The following preliminary report was prepared by Professor Lord:

In the jacket which carries the two-prism star spectroscope of the Emerson McMillin Observatory (see this JOURNAL, Vol. IV, No. 1) was securely fastened the tube of a 4-inch Clark telescope of about 60 inches focus. This formed an image of the solar crescent at the point ordinarily occupied by the slit. The jacket itself was screwed into a cast-iron ring similar to the breach piece of the 12-inch telescope, except that at the opposite ends of a diameter there were two trunnions fitting into boxes securely bolted to the heavy wooden stand that carried the instrument. Thus the whole spectroscope could be rotated about the axis of collimation of the 4-inch objective, and at the same time the entire instrument, objective and all, could be rotated a small amount about a line at right angles to it. At a point midway between the two trunnions a lug projected from the supporting ring, which carried at its extremity a screw, whose axis was perpendicular to the plane of the ring and whose end butted against the support of the instrument. This screw served not only to rotate the entire instrument about a line perpendicular to the axis of collimation but also gave a rough means of measuring the amount of this rotation. The 4-inch telescope was fed by a most excellent coelostat, kindly furnished by the Naval Observatory. The axis of the trunnions was placed perpendicular to the line joining the points of the second and third contacts as seen in the mirror of the coelostat. Thus it was possible during totality, first, by a rotation of this screw, and second, by a rotation of the spectroscope in its jacket, to so move the instrument that the image of the point of third contact could be made to fall accurately at the point ordinarily occupied by the center of the slit, and, at the same time, to bring the image of the tangent to the solar crescent at this point parallel to the refracting edge of the prism. At Barnesville, though the change in position angle was considerable, it was decided not to attempt the second change but simply to shift the instrument during totality from one limb of the Sun to the other, one and a quarter turns being necessary.

In order to check all adjustments the telescope which receives the light reflected from the front face of the first prism and is used for following in photographing stellar spectra had two wires placed in its eyepiece, one parallel and one perpendicular to the slit. Thus before totality the instrument could be accurately directed to the point of second contact. During totality the screw was given a turn and a quarter by estimation, and when examined after the eclipse through the following eyepiece the point of third contact was found accurately at the intersection of the two wires.

The framework which carried this somewhat heavy piece of apparatus was built of heavy timber in the form of an isosceles triangle, having two uprights at the center of each leg to which the boxes of the iron ring were fastened. The vertex of the triangle extended about 18 inches in front of the 4-inch objective and was pivoted under the center of the coelostat mirror. The base rested on a heavy beam. Thus the entire instrument could be rotated in azimuth through an angle of about 30°. In this way, not only could the Sun be followed from day to day but bright stars could be photographed for purposes of adjustment. To show the necessity of such a plan of adjustment I will only state that within 10 minutes of totality, as I gave a last look at my adjustments, I discovered that the Sun's image was not exactly centered and it was necessary to move this entire framework; this was successfully done in ample time for the second contact.

I desired to secure a number of photographs both before and after the flash. In order to accomplish this I fitted a sliding plate-holder to the end of the camera. This consisted of a slide carrying the plate-holder mounted on bicycle balls, which traveled in V-shaped ways. The slide was forced against these by means of two wheels kept pressed against the back face of the slide by a couple of spiral springs. The carriage carried an escapement operated by a pneumatic release, so that by pressing a bulb the plate was automatically shifted $\frac{1}{16}$ of an inch in less than $\frac{1}{3}$ of a second. The size of the picture was $\frac{1}{2} \times 2$ inches. The jar was taken up by a sliding brace from the end of the camera to the solid woodwork of the frame, so designed that it was only necessary to clamp or loosen a single thumbscrew to make the brace either rigid or flexible in every direction. The carriage was so mounted that it could be tilted in a direction parallel to the length of the spectrum in order to accommodate outstanding chromatic aberration.

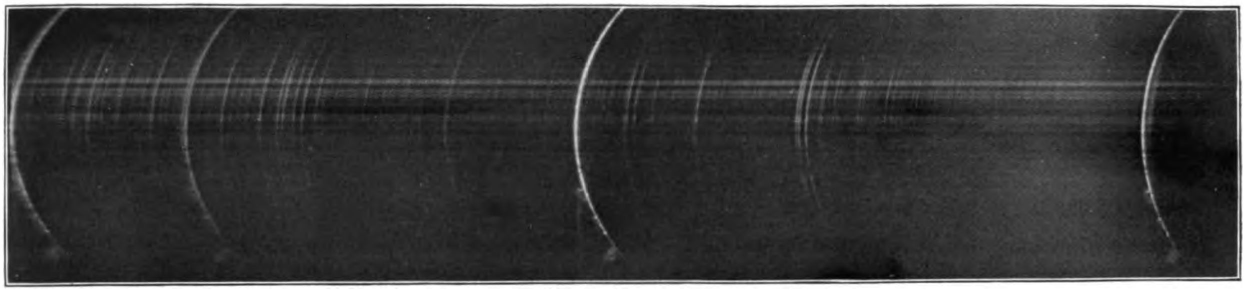
In front of the objective a rough wooden shutter served for purposes of exposure. The shortest exposure possible was about $\frac{1}{3}$ of a second, which, however, the plates show was much too long for the solar crescent before totality.

After a good many trials I was convinced that it would be impossible to follow any time schedule for exposures and I adopted a suggestion made by Dr. Crew to watch for the flash and expose when I saw it, making one or two

exposures before and after, those preceding the flash to be as short as possible. As I had no additional spectroscope, it was necessary to build one out of what extra apparatus I happened to have. To do this, I used a 60° dense flint prism and the observing telescope of the spectroscope. This prism was mounted as an objective prism, the whole in a rough alt-azimuth stand. It worked most satisfactorily, as the entire process of the change, from the continuous spectrum long before totality to that of mid-totality, was easily observed and constituted one of the most beautiful sights that I ever hope to witness. I did not attempt to secure the times at which the exposures were made as I had no means of automatically recording them.

The program of exposures as actually carried out was as follows: With the string which operated the exposing shutter in one hand and the bulb which shifted the plates in the other, I watched the spectrum through the objective prism spectroscope. By six and one half minutes before totality the dark $H\beta$ line was faintly shown; three minutes later numerous lines began to appear. Shortly before totality $H\beta$ was brilliantly reversed and exposure No. 1 was made. The spectrum then rapidly narrowed and plate No. 2, snap exposure (about one third second) was made. The spectrum continued to narrow until it suddenly broke up into a number of bright strips extending the length of the spectrum; with this came the flash, and No. 3 was exposed. I had intended at this point to leave the objective open until the flash disappeared, but habit was stronger than purpose, and I involuntarily made a snap shot at this point. I instantly remembered myself and again opened the objective, so I feel safe in saying that I did not lose over one third of a second by this mistake. It is, however, in my judgment, rather fortunate that this accident happened, as it throws some light on the duration of the flash. Plate No. 6 had full exposure on the flash, and yet does not show much greater exposure than 3, which would tend to show that the duration of the flash was considerably under one second. The appearance of the flash itself was very peculiar, though the entire phenomenon was excessively short. My notes made at the time say, "Could not have been over one second." It was not fixed while it lasted, but the lines seemed to twinkle. As soon as the flash disappeared exposure No. 4 was made for about three seconds. As the slide was only arranged for four exposures, the plate-holder was changed, the slide set, and the instrument directed to the point of third contact. So intent had I been on watching the spectrum through the objective prism that I had been oblivious to the count, and fearing I was late I listened and heard 33–34 with a great sense of relief. I at once opened the 4-inch, thus exposing No. 5, and turned to look at the corona, which I watched until 60 was called. When I turned back to the objective prism I was at once struck with the great brilliancy of the $H\beta$ line, which showed several well-marked prominences, when I felt it was time to shift the plate without closing the 4-inch, and this exposure

PLATE V



SPECTRUM OF THE SECOND FLASH

PHOTOGRAPHED WITH OBJECTIVE-PRISM TRAIN BY H. C. LORD

was continued as long as seemed safe and until the flash was well developed. The objective was then capped and the plate shifted, but I made a double shift at this point, so that I had but one plate left to expose after the third contact. This exposure was made almost immediately following the flash; it was of about one third of a second duration, and is No. 8 on my list, No. 7 being a blank.

The plates were not developed until after my return to Columbus. The most noticeable feature common to all was the great amount of continuous spectrum. This was certainly *not* due to the light leaking through the apparatus, as this point had not only been carefully tested, but the portions of the plate between exposures showed not the faintest trace of fog. Plate No. 1 was much overexposed, but showed in addition to a number of the dark Fraunhofer lines the $H\beta$ brilliantly reversed on the edges and dark in the center. The dark $H\beta$ fades into the bright one, but the lines do not butt against each other, but overlap so that for a considerable extent the bright and dark lines are seen side by side like the pieces of a spliced rod, except that the prolongation of the dark line does not pass through the center but to one side of the bright line. The same thing is shown in a few of the other lines, but is not nearly so well marked. No. 2 shows a number of bright lines bordering a continuous overexposed spectrum containing only a very few dark lines. D_3 is bright clear across the continuous spectrum. No. 3 is the flash and shows 150 lines from D to near $H\gamma$. No. 4 shows only a very few bright lines. No. 5 the same. No. 6 is the flash at third contact and shows over 157 lines. (Plate V.) No. 8 shows quite a number of bright lines bordering the continuous spectrum, which, as in No. 2, shows almost no dark lines.

The visual observations of Mr. Jewell at Griffin, with a small grating binocular, are interesting and valuable, as the long duration of the reversing layer so near the limit of totality gave time for observing carefully the gradual appearance and disappearance of the bright lines of its spectrum. The instrument consisted of a plane grating, one inch square, of 15,000 lines, and a small plane metallic reflector in combination with a field glass magnifying three diameters.

At five minutes before totality the Fraunhofer lines were arranged in dark narrow crescents, too bright in the yellow to observe comfortably, and observations were confined to the blue-green region in the vicinity of F.

At two and one half minutes before totality the F line was seen tipped on the lower end with a bright point which spread gradually upward, and a minute later a similar appearance was noticed on the upper horn. The spectrum band gradually narrowed, until five seconds before contact the arcs of the Fraunhofer spectrum embraced about

one fourth of the Sun's diameter. At three seconds before contact the mountains of the Moon began to break through and cut across the crescents, and an observer stationed near by signaled the appearance of the shadow on a range of hills six miles distant. At the same time many of the fairly strong lines became brightly tipped at the ends of the crescents; the Fraunhofer spectrum began to narrow rapidly, until when a very narrow ribbon was left it changed to a bright streak which seemed to remain thus for about a second and then disappeared.

At this instant the signal for totality was given, which coincided exactly in time with that given by myself observing with a six-inch telescope. The field of the spectroscope was now literally filled with bright crescents of various lengths which faded out very gradually, many of them lasting eight or ten seconds after second contact, and a few even longer.

At mid-totality the F line was visible, forming a bright arc of from two thirds to three fourths of a complete circle, as well as several other much fainter lines including the *b*'s.

At ten seconds before the third contact other bright lines began to appear, and the phenomena at the beginning were repeated in reverse order.

The appearance and disappearance of the fine bright short lines was not instantaneous, but gradual. The narrow bright streak seen at the instant of both contacts was without doubt the narrow band of short bright lines shown in the photographic spectrum of the reversing layer at second contact, due in great part to matter at a height of 100 to 300 miles above the photosphere, along with a considerable amount of continuous spectrum.

These observations, taken in connection with the statement of Dr. Gilbert, that the exposure for the spectrum obtained at the second contact *ended* just before the last rays of direct sunlight disappeared — and the further evidence of the large scale photographs showing the base of the chromosphere and a very small portion of the photosphere — indicate that the chromosphere at its base is very dense and bright, and weakens gradually towards its upper limits, at its base merging gradually into the upper limits of the photosphere.

The great advantage of a station near the outer edge of the shadow path is shown by the ease and distinctness with which the spectrum of the chromosphere was observed at Experiment, compared with the failure of two observers at Pinehurst, using instruments of identical

construction, to see it at all, and the experience of Professor Lord at Barnesville, who observed it with a more powerful instrument, a prismatic camera, but found it surprisingly faint.

Of visual observations, besides the observations of contacts, naked-eye and telescopic drawings of the corona were secured, three of which are of much merit. These, as well as all the photographs, show the striking similarity between the coronas of 1878 and 1900.

Observations of the shadow bands were secured at many places from Georgia to the coast. While some of the observations are apparently conflicting, there seems to be no doubt from a study of their irregular structure and motion at the many stations that they are of purely atmospheric origin, and will probably find their explanation in the same causes that produce the twinkling or scintillation of the stars.

S. J. BROWN.

A PRELIMINARY STATEMENT OF THE RESULTS OF THE SMITHSONIAN OBSERVATORY ECLIPSE EXPEDITION.[1]

IN accordance with a special act of Congress, the Astrophysical Observatory of the Smithsonian Institution was enabled to send an expedition to observe the total eclipse of May 28, 1900. This expedition was directed and the preliminary arrangements for it were made by Mr. S. P. Langley, Secretary of the Smithsonian Institution, the field work and immediate supervision being in charge of the writer. The party consisted of fourteen persons, and the site chosen for the observations, which was selected not only after consideration of the Weather Bureau's reports for the eclipse belt, but also after a careful examination of various localities, was Wadesboro, N. C. The instruments and equipment were placed upon ground most generously offered for the purpose by John Leak, Esq., of Wadesboro, to whom and to many other citizens of the town are due hearty thanks for the hospitality enjoyed there by the large number of visiting astronomers. The Yerkes Observatory party was on the same ground, and there were also in Wadesboro expeditions from the Princeton Observatory and from the British Astronomical Association, making in all a most pleasant international gathering.

As the most thorough preparation and drill was recognized by Mr. Langley to be one of the prime conditions to success in eclipse observations, several months were almost wholly devoted to preparing for

[1] Published by permission of the Acting Secretary of the Smithsonian Institution.

the expedition. The whole outfit was set up upon the green south of the Smithsonian building, in Washington, early in April, and preliminary experiments and even two practice eclipses, in which actual photographs were taken, were carried through there. The apparatus was removed to Wadesboro very early in May and reached the grounds May 7, and here also all things were tested and drilled, that nothing might be lacking to a satisfactory result. On the morning preceding the eclipse a "full-dress rehearsal" took place, at which every detail was attended to as if the phenomenon was actually occurring, Mr. Langley remarking that if a pin was going to fall and be picked up during the eclipse it should be dropped and picked up for practice in that rehearsal.

The main object of investigation of our party was the corona, and of this it was desired, first, to obtain large-scale photographs of the inner details, with other photographs showing the extent of the corona, and second, to examine the inner corona with the aid of the bolometer to obtain thermal evidences of coronal radiations and, if possible, of the form of its prismatic spectrum energy curve.

In addition to these investigations, five cameras of large field were used to photograph the region around the Sun, visual telescopic observations and sketches were made, and the times of contacts were observed visually and with a camera exposed each second by a chronometer. An objective prism used in connection with the 135-foot focus camera was used also with an automatic exposure to obtain the flash spectrum at second contact.

Before proceeding further it may be said that all these investigations yielded interesting results excepting the last, which from some unknown cause was unsuccessful.

I will now briefly describe these several kinds of observations, the instruments employed in them, and their results.

I. DETAIL PHOTOGRAPHS OF THE INNER CORONA.

Mr. Langley had long been specially interested in the details of structure of the inner corona in consequence of the surprising definiteness in this respect noted by him in visual telescopic observations made at Pikes Peak in 1878. While knowing and admiring the fine photographs of Campbell, and earlier of Schaeberle, with a 5-inch 40-foot focus lens, it was his belief that still more of structure might be obtained with an instrument of greater aperture and focal length. He

PLATE VI

THE NORTH POLAR STREAMERS OF THE CORONA

PHOTOGRAPHED WITH A 12-INCH TELESCOPE OF 135 FEET FOCAL LENGTH BY T. W. SMILLIE

was on the point of ordering a lens of 8 inches aperture and 60 feet focus for this purpose, when he received the extremely welcome offer of Professor E. C. Pickering of the loan of the new 12-inch achromatic lens of 135 feet focus belonging to the Harvard College Observatory. At the same time, Professor Pickering offered several other pieces of optical apparatus, including that for the automatic flash spectrum with the objective prism. It is needless to say that this most generous offer was accepted.

In addition to the great 12-inch lens, one of the set of "Transit of Venus" lenses, of 5-inch aperture and 38-foot focus, was used through the kind offices of Professor Young, of Princeton.

The former was employed as a horizontal telescope in connection with the 48-hour polar axis type of coelostat carrying an 18-inch plane mirror, while the latter was pointed in a stationary position toward the sky and the photographic plate moved in the focus by a water clock. The first instrument had 30-inch square plates, and was manipulated by Mr. T. W. Smillie, of the United States National Museum (who also had general charge of photography, including the development of all plates), and the second, employing 11 × 14 plates, was in charge of Mr. F. E. Fowle, Jr. The plates used, not only in this but in all the photographic work, were Cramer double coated isochromatic plates, not backed. They were extremely rapid, being for general purposes nearly twice as fast as Seed's 26x ordinary.

Six exposures were made by Mr. Smillie during totality, ranging from ½ second to 16 seconds. All these were entirely successful. Three others made after totality showed little of interest. The illustration (Plate VI) is from a print of the 16 seconds exposure. All the original plates (on a scale of 15½ inches for the Moon) are full of detail, the prominences being very striking. There seems to be no question that the details are more numerous than those shown upon the smaller scale of the 38-foot lens.

Mr. Fowle obtained seven negatives with this latter instrument during totality, all of which are excellent. The times of exposure varied from ½ to 8 seconds. The 8 seconds exposure shows the corona somewhat further than the 16 seconds exposure with the great lens.

II. BOLOMETRY OF THE INNER CORONA.

This was in the hands of Mr. C. E. Mendenhall and myself, he reading at the galvanometer, I manipulating the optical apparatus. As

the results obtained seem to be of importance in their bearing on the composition of the corona, a diagram of the apparatus is inserted (Plate VII) that a clear understanding of the experiment may be obtained.

The light from the Sun, falling upon the plane siderostat mirror of 17 inches aperture, passed first through a cats-eye diaphragm of gray cardboard controlled by Mr. Mendenhall. Thence it fell upon a 50 cm mirror of 1 m focus, and came to a focus upon the slit, 1 cm high, 1 mm wide, in the optical axis of the mirror. Behind this slit was a little plane mirror which reflected the beam out of the path of the entering light to a second plane mirror, thence to a concave, of 26 cm aperture and 75 cm focus, acting as a collimator.

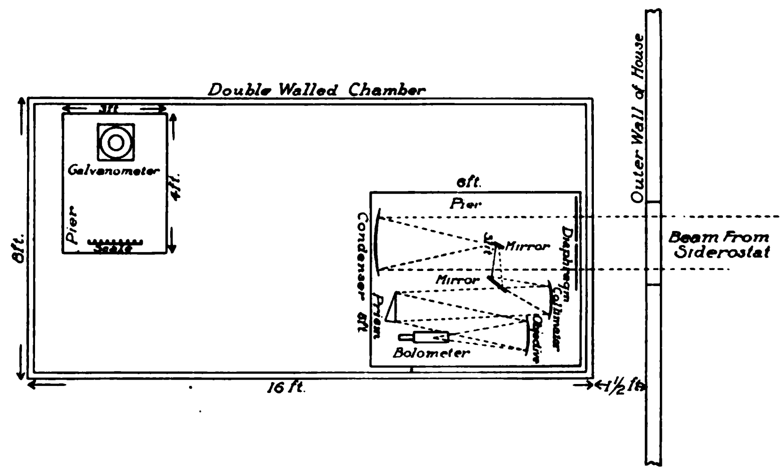
Thence the beam passed to the prism silvered on one face which was intended to serve either of two purposes as desired: to refract or merely to reflect the beam to the mirror of 26 cm aperture and 75 cm focus which formed the image on the 1 cm high, 1 mm wide bolometer strip. There was no plate of glass or other material in front of the bolometer during the experiments, as the galvanometer was found steady enough without, nor was any water in the bolometer water-jacket, as no "drift" was encountered. The case of the bolometer had a conical blackened opening just taking in the cone subtended by the image-forming mirror. A dark gray card was sometimes inserted before the bolometer to give a zero reading. The resistance of the bolometer strip was 0.5 ohm and the current flowing through it 0.2 ampere. The strip was well smoked with camphor smoke.

I have been thus particular to specify details, as I regard them necessary to an intelligent criticism of the results to be described.

About five minutes before totality the image of the diminishing crescent was brought almost tangent to the bolometer strip, and the silvered face of the prism turned to the beam. With the diaphragm aperture at 0.4 sq. cm, galvanometer deflections diminishing from + 60 to + 6 mm were obtained in the next few minutes, the last being about 40 seconds before second contact. The zero of the series was obtained by inserting the gray card above mentioned.

Immediately after totality, the diaphragm having been enlarged to 280 sq. cm aperture, a deflection of — 13 mm was obtained in the same place, *i. e.*, the inner coronal region, and upon turning the Moon's

PLATE VII



BOLOMETER HOUSE OF THE SMITHSONIAN PARTY

dark image upon the slit by means of the adjusting screw of the condensing mirror, a deflection of — 18 mm was observed.[1]

Resetting upon the inner corona, the glass face of the prism being now turned to the beam, and H and K of the spectrum being on the bolometer, no deflection was observed.

These observations seem to me to yield the following results:

1. The coronal radiation was recognized by the bolometer, and gave at least 5 mm deflection over that of the dark Moon.

2. The radiation reflected by the Earth's atmosphere during the partial phase is vastly more intense than that of the corona.

3. *The corona is effectively cooler than the bolometer, and appears, therefore, neither to reflect much light from the Sun nor chiefly by virtue of a high temperature to give light of its own, but seems rather to be giving light in a manner not associated with a high temperature, or at least with the preponderance of infra-red rays usual in the spectra of hot bodies.*

As the last statement involves a rejection of both the eruptive and meteoric coronal theories, it ought to receive searching criticism, and the experimental observations on which it rests ought to be verified at future eclipses. The statement depends on the following experimental evidence:

The corona gave a negative deflection with respect to a card and to the walls of the room as reflected by the glass prism surface, both being supposed to be at the same or a lower temperature than the bolometer strip. From this it follows that the bolometer strip was losing energy by radiating toward the corona, not the corona toward the strip. That the card, the walls of the room reflected by the glass prism surface, and the bolometer were all of the same temperature, is open to question. But they were all in a fairly constant temperature double-walled room, close together, and all at the same height from the ground. The bolometer strip, however, may probably have been a little *warmer* than the others, for it had constantly passing through it the current of 0.2 ampere. Hence it would appear most probable that the card reading was not the true zero which would be given by a body at the temperature of the bolometer, but a negative value, and

[1] Owing to a slight maladjustment of the condensing mirror not noticed till it was too late to change, the image of the Moon fell a little too low at the slit, so that a little of the polar corona fell on the bolometer strip during the Moon exposure, and hence the negative deflection of 18mm should be numerically increased slightly.

that in consequence the negative deflection recorded from the corona should have been numerically still larger.

I am unaware of quantitative experimental investigations on the heating effects of radiations emitted from the spark and glow electrical discharges in high vacua, from phosphorescent substances, from so-called luminescent substances, from the aurora and other such supposedly cold sources, excepting the investigation[1] of S. P. Langley and F. W. Very on the "Cheapest Form of Light," in which they show a nearly complete absence of radiations other than visible ones from the tropical insect *Pyrophorus Noctilucus* Linn. But it is generally supposed that the quality of radiations emitted by the sources of light I have mentioned is not similar in nature to that of heated bodies in having associated with the light emitted a preponderance of long wave-length rays.

It is hoped to investigate here the glow and spark electrical discharges with a view to their possible bearing on the coronal observation I have just recorded.

It may not appear conclusive to some that these results are inconsistent with the supposition that the corona gives light by reflection, or by the radiation of heated particles, nor do I wish to make a dogmatic statement to this effect. Evidently it is not inconsistent with the experiment that a small portion of the coronal light may be due to these sources, but that most of it is thus caused I am unable to reconcile with the observations. For we know that the full Moon is intrinsically less bright than the inner corona and the daylight sky not much more bright. Both these bodies give light by reflection from the Sun, and both give large positive deflections with the bolometer, chiefly caused by the preponderating amount of infra-red rays they reflect. How then can the corona be composed of particles sufficiently numerous to give a practically continuous surface brighter than the Moon if it shines by light reflected from the Sun, and not give a large positive indication at the bolometer? Again, as regards incandescent particles, we know that white light due primarily to high temperature is invariably associated with a far larger proportion of infra-red rays. How is it possible that incandescent particles sufficiently numerous to give the coronal light should not give bolometric evidence of their high temperature, but rather give the appearance of being cold?

The bolometric study of the Moon may suffice to illustrate either the reflection or incandescence theories. For the Moon is but a mirror

[1] *Am. Jour. Sci.*, 40, 97, 1890.

reflecting light from an incandescent body, the Sun. The bolometric studies of Langley (*Mem. Nat. Acad. of Sci.*, Vol. III, p. 24, 1884) have shown that with fairly similar arrangements to those used at Wadesboro the full Moon's reflected visible rays plus her reflected invisible rays gave enormous positive deflections. How then can a beam from the corona containing at least an equal amount of visible rays give so much less a deflection, except the infra-red rays be absent? If this be the explanation, the radiations of the corona are not of the quality ordinarily emitted by a heated body.

Additional evidence against the theory of reflecting particles is found in the Indian eclipse spectroscopic results of Campbell, who found a continuous spectrum from the inner corona with total absence of dark lines.[1]

If, then, an investigation of glow electrical discharges in high vacua should be found to yield effects approximating those of the corona, it would seem plausible to adopt this explanation of coronal light.

III. PHOTOGRAPHS OF THE OUTER CORONA AND SKY NEAR THE SUN.

Four photographs of the outer corona were obtained. The instruments used were: first, an equatorial of 6 inches aperture and 7½ feet focus, in charge of Mr. De Lancey Gill, used with color screen cutting off the violet; second, two Ross lenses of 4½ inches aperture and 3½ feet focus, one of which had a color screen; and, third, one of a pair of 3-inch lenses of 11 feet focus. The two Ross lenses and the two 11-foot lenses were mounted on a polar axis with excellent clockwork and were designed to search for possible objects of interest near the Sun. They were in charge of Rev. G. M. Searle, C.S.P., assisted by P. A. Draper and C. Smith. Incidentally they give a test of the advantages of the long and short focus for star photographs on a fairly light sky. All the instruments just mentioned were given an exposure of 82 seconds.

The four coronal photographs showed an extension of about three diameters, that with the 7½-foot focus lens being slightly longest while that with the 11-foot focus lens showed best detail.

The two 11-foot focus lenses (covering together a field of $25° \times 10°$ or thereabouts in the equatorial region of the sky) showed most stars, reaching, I think, the seventh magnitude and possibly fainter. The Ross lenses got no farther than the sixth magnitude, but their plates were not as favorably developed. No search has yet been made for new objects.

[1] This JOURNAL, April 1900.

IV. VISUAL OBSERVATIONS.

Visual observations of the corona were made by Secretary Langley, observing, through the courtesy of Professor S. J. Brown, astronomical director of the Naval Observatory, with the 5-inch equatorial formerly used by him on Pikes Peak and reëmployed with the especial intention of enabling him to compare his observations on this occasion with those made in 1878, and by Mr. R. C. Child, with a 6-inch equatorial. Their observations showed little detail in the coronal structure compared with that formerly noted. Mr. Child, before having seen photographs, prepared from his sketches an excellent picture in pastel of the corona, and this is strikingly like the photographs subsequently developed.

Mr. G. R. Putnam, of the Coast Survey, detailed for latitude and longitude observations, determined times of contact and gave signals to the other observers. It appears from his observations and those of Rev. Fr. Woodman that the duration of totality was not appreciably different from that which had been computed from the American ephemeris. Mr. Putnam's latitude and longitude, the result of five nights observations with a reversible meridian transit instrument, was as follows:

Latitude, 34° 57′ 52″ North.

Longitude, 80° 04′ 27″ West of Greenwich.

The photographic time of contact results are not as yet reduced.

On the whole the results of the expedition are satisfactory. Those of chief importance now appear to be:

1. The bolometric examination indicates that the coronal light is not chiefly due to reflecting or incandescent particles, and that its radiations, though measurable, are extremely slight.

2. The 12-inch 135-foot telescope with coelostat proved well adapted to securing detailed photographs of the inner corona, and six excellent photographs have been obtained with this instrument.

3. The plan outlined in a recent Harvard College Observatory *Circular* for photographing faint objects in the sky near the Sun at the time of the eclipse gave good results in practice, seventh and possibly eighth magnitude stars having been photographed over a region 25° × 10° in the direction of the Sun's equator.

C. G. ABBOT.

SMITHSONIAN ASTROPHYSICAL OBSERVATORY,
Washington, D. C., June 30, 1900.

ECLIPSE OBSERVATIONS BY THE PRINCETON PARTY AT WADESBORO, N. C., MAY 28, 1900.

IN this short notice I confine myself to the mere statement of results, without unnecessary details as to instruments, corrections applied, etc.

The weather was almost ideally perfect. What wind there was was very light and changeable.

CONTACTS.

The first contact was observed by myself with 3-inch Fraunhofer at $7^h\ 36^m\ 02^s$. E. St. time; by Professor Reed with 4-inch telescope at $7^h\ 36^m\ 01^s.4$; by Mr. Russell, spectroscopically, by disappearance of C-line in chromosphere spectrum, at $7^h\ 35^m\ 57^s.4$. A series of photographs were also taken by Professor Brackett and Mr. McClenahan with the 12-foot telescope (aperture cut down to 4 inches). The negatives have not yet been measured, but show that *photographic* contact occurred between $35^m\ 54^s$ and $36^m\ 04^s$, the indentation on the Sun's disk being barely perceptible upon the negative taken at the latter moment.

The time of contact, computed from the data of the American Ephemeris, was $7^h\ 36^m\ 09^s.3$, *i. e.*, $7^s.6$ later than the mean of Mr. Reed's observation and my own.

The times of second and third contacts were not noted with precision, as all the observers were otherwise engaged.

The fourth contact was observed by me at $10^h\ 05^m\ 39^s.9$, and by Mr. Reed at $05^m\ 39^s.6$. The observation was easy and very satisfactory. Mr. Russell noted it spectroscopically, as before, at $05^m\ 41^s$. The computed time was $10^h\ 05^m\ 43^s.0$, the difference between computation and observation being now only 3¼ seconds.

A series of photographs of the last contact was also taken by Professor Brackett at intervals of 10 seconds. As it was inconvenient, on account of the elevation of the telescope, to make "instantaneous" exposures, the exposures were made of about half a second each, giving *positives* (not *negatives*) of the Sun's disk. The photographs are sharp, and clear, and show by inspection (they are not yet measured) that the contact occurred very nearly at $10^h\ 05^m\ 40^s$. The Moon's indentation is clear on the plate exposed at $05^m\ 34^s$, and has disappeared at $05^m\ 44^s$.

PHOTOGRAPHS OF THE CORONA.

With the 12-foot telescope (driven by clockwork) six photographs of the corona were obtained by Professor Brackett and Mr. McClenahan, with exposures of 1^s (2 plates), 5^s, 10^s, 20^s, and 4^s, the last just as the Sun was reappearing. All except the 5^s negative are good. Professor Libbey had three cameras mounted on a single clock-driven polar axis, one with a landscape lens having an aperture of 4 inches; the other two, photographically corrected telescopic object glasses, with an aperture of 2¼ inches, all having focal lengths ranging 30 to 32 inches. With these he obtained 11 negatives with exposures of 20^s, 10^s, 5^s, and 1^s. The landscape objective (used without a stop) did not perform well for the purpose, but the other negatives are all good, and the 20^s-plate shows the faint extensions of the corona to a distance of two and a half solar diameters, about two thirds as far as the eye could follow them; that is to say, on the photograph the western fish-tail of the corona extends about half way to the planet *Mercury*, while the eye could follow it at least three-quarters of the distance, and with the long, pointed, eastern cone the case was similar.

DRAWINGS OF THE CORONA AND PROMINENCES.

During the totality Professor Magie studied the region near the Sun's limb with the 4-inch telescope with special reference to the connection between the prominences and the corona, and to the details of the coronal filaments where they issue from the Sun. Very little, however, could be made out. The sketches of the corona show an unusually close correspondence with the form shown on the photographs.

THE FLASH-SPECTRUM.

This was observed by Professor Miller, of Cleveland, O., with a slitless spectroscope having the dispersive power of two 60°-prisms of 2 inches aperture, and a small telescope magnifying 11 times. He did not see any very large number of bright lines, though the transition from the dark-line spectrum to the bright lines was sharply marked, and at that moment he gave the signal as the beginning of totality. At mid-totality eight bright rings were visible, but all of them were incomplete—open for about 40° or 50° on the western edge. The explanation is not yet obvious. The "rings" seen were, however, probably all of them chromospheric except the one in the green.

OBSERVATIONS OF THE CORONA SPECTRUM.

These all failed; that is, neither Mr. Russell nor myself could see the bright line of the corona spectrum, nor could Professor Reed get its impression on his photographic plate. The line was doubtless very much fainter than in 1869, 1870, and 1878, when I had not the least difficulty in observing it with an instrument certainly not superior to that used by Mr. Russell. I had not anticipated any such difficulty on this occasion, and the program had been planned with reference to getting a good determination of the line's position rather than merely making it visible.

I worked with an integrating spectroscope, with a diffraction grating of 14,000 lines to the inch, using the second order spectrum, which was very bright. At Princeton I had no difficulty on cloudy days in observing with this instrument the dark 1474 line in the sky spectrum; but during totality I saw absolutely nothing except a very faint continuous spectrum even when the slit was opened to its widest.

Mr. Russell's experience was similar, using an ordinary solar (grating) spectroscope, attached to a telescope of five inches aperture. Before totality began, 1474 and the *b*'s were conspicuously reversed, and at the moment totality began, some fifteen or twenty other lines in the field of view became bright for a second or two — but the corona line did not appear at all: the field was blank, except for the faint continuous spectrum.

Professor Reed's instrument had the same train of four compound prisms which had been loaned to Professor Campbell in 1898, and used by him successfully in photographing the corona line in the Indian eclipse — the plate showed nothing. Possibly the slit was too close — the comparison spectrum was beautifully sharp — and very likely, if we could have had an exposure of six minutes instead of only ninety seconds some impression might have been made.

THE SHADOW BANDS.

These were satisfactorily observed by Mr. Reilly, Mr. Erdman, and Mr. Meier upon two tent-flies, one inclined and nearly facing the eclipsed Sun, the other lying upon the ground. The bands first appeared about a minute and a half before totality, lying in a plane nearly tangent to the uneclipsed arc of the Sun's limb, about two inches wide, but wavy and irregular, separated by an interval of from five to seven inches, and moving with a speed of about five or six miles

an hour, in a direction from southwest to northeast. As totality approached, the interval between the bands diminished, till they were only an inch or two apart, and the speed of their apparent motion increased enormously — to the velocity of an express train. After totality they were more irregular, close together, with no decided progressive motion, but simply quivering or oscillating. They lasted about a minute and a half before fading out. Mr. Reilly attempted to photograph them upon the inclined tent-fly, but got nothing.

It is noteworthy that the motion (real or apparent) observed at our station before totality was exactly opposite in direction to that noted by the Smithsonian observers less than a quarter of a mile away.

C. A. YOUNG.

PRINCETON, N. J.,
June 30, 1900.

THE YERKES OBSERVATORY OF THE UNIVERSITY OF CHICAGO.

BULLETIN NO. 14.

OBSERVATIONS OF THE TOTAL SOLAR ECLIPSE OF MAY 28, 1900, AT WADESBORO, N. C.[1]

THE Yerkes Observatory eclipse party occupied an excellent site adjoining that of the Smithsonian Institution at Wadesboro, N. C., for the use of which we are indebted to Mr. John Leak. The latitude of the site was determined by Professor A. S. Flint, of the Washburn Observatory, who was a member of our party, but as his observations are not yet reduced, the results here given are based upon the following determinations of position made at the Smithsonian site by Mr. G. R. Putnam of the U. S. Coast and Geodetic Survey:

$$\phi = 34^\circ\ 57'\ 52''\ \ \text{N.}$$
$$\lambda = 5^h\ 20^m\ 17^s.88\ \ \text{W}$$

[1] As it was not definitely known until after the middle of April that it would be possible to send out an eclipse expedition from the Yerkes Observatory, the work of preparation was very hurriedly done. For this reason the instrumental equipment was less complete than it would otherwise have been, and many appliances for facilitating the observational work could not be provided. Special credit is due to Mr. G. W. Ritchey, Superintendent of Instrument Construction, not only for designing most of the instruments and buildings required, but also for superintending their construction at a time when the optical work demanded his constant attention.

CONTACTS.

Contacts were observed by Professor Flint from a station near the coelostat with a 3-inch equatorial of 46 inches focal length, power 50. The chronometer, Bliss 2791 on sidereal time, was loaned by the Washburn Observatory. The observer's primary duty was to call out every 5 seconds of elapsed time for control of the spectroscope exposures made by Professor Frost and Dr. Isham. Beginning at the first stroke of the signal of five bells (sounded by Mr. Putnam), which was to mark an interval of 60^s preceding the computed time of second contact, a count was made at the chronometer beat, starting at 0^s. At 60^s, or at computed second contact, the call was started, again from 0^s. During totality two comparisons were made of the count with the chronometer readings, and two others were made after third contact. A part of the record, including the last two comparisons, is unintelligible, but the later comparisons agree with the second in showing that the difference between the chronometer and the count was a multiple of 5^s. Hence, in the first comparison, although the seconds are recorded as 46^s, they are assumed to be 45^s. The chronometer corrections to reduce to sidereal time of station were computed from comparisons with the Washington noon signals.

OBSERVED TIMES OF CONTACTS, MAY 27.8, 1900, ASTRONOMICAL MEAN DATE.

Contact	Chron. Time.	Correction	Local Sidereal Time	Local Mean Time
	h m s	m s	h m s	h m s
1st	23 37 49.	+0 33.4	23 38 22.4	19 15 59.5
2d	0 47 03.0	+0 33.6	0 47 36.6	20 25 2.3
3d	0 48 30.	+0 33.6	0 49 3.6	20 26 29.1
4th	2 7 30.	+0 33.8	2 8 3.8	21 45 16.3

Contact	Gr. M. T. Observed	Gr. M. T. Computed	O—C
	h m s	m s	s
1st	0 36 17.4	36 10.	+7.
2d	1 45 20.2	45 23.6	—3.4
3d	1 46 47.0	46 55.6	—8.6
4th	3 5 34.2	5 43.	—9.
	1 26.8	1 32.0	—5.2

No significance is attached to the tenths of a second except in the case of the second contact.

PHOTOGRAPHS OF THE CORONA.

The corona was photographed with eight lenses as described below.

The principal instrument was a horizontal telescope of 61½ feet focus, fed by a coelostat. The 6-inch photographic objective of this telescope was made by Brashear, and gave photographs of the corona on a scale of 13 inches to the degree. The coelostat was constructed in the instrument shop of the Yerkes Observatory under the supervision of Mr. Ritchey, who himself made the very perfect silvered plane mirror of 12 inches aperture. The same mounting carried a 15-inch plane mirror by Petitdidier for Professor Frost's spectroscopic work. The 6-inch objective was connected with the photographic house by a long light-tight tube, shielded from the Sun's rays by a white cotton screen, and fitted throughout with diaphragms to prevent internal reflections. The light-tight photographic house, 6 feet wide and 30 feet long, stood with its long axis perpendicular to the tube. In order to facilitate handling the large photographic plates employed, they were mounted on a wooden carrier 15 feet long, free to move on ball bearings on a steel track extending the entire length of the photographic house. In this carrier the plates were all placed at an angle equal to the latitude, so that the long axis of the plates was parallel to the celestial equator. A catch operated by hand served to stop the carrier at the proper place for each exposure.

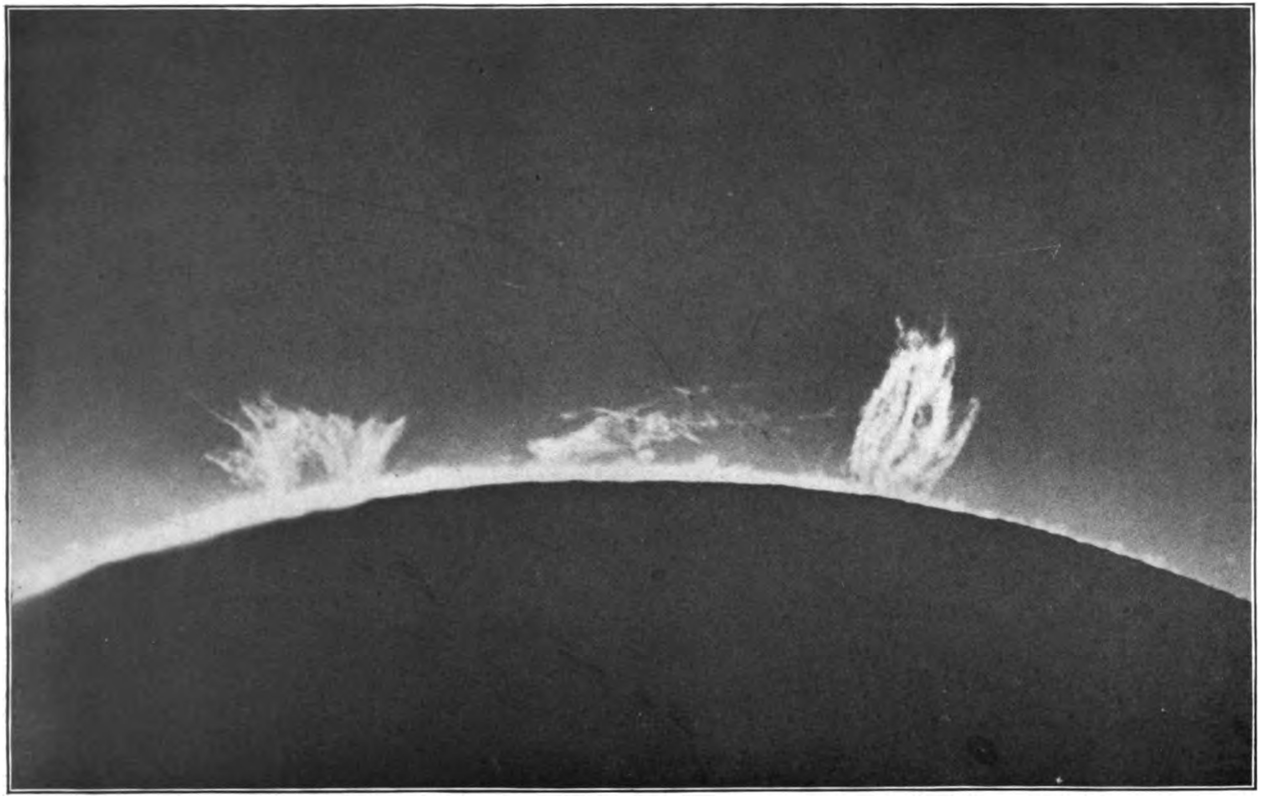
With this apparatus seven plates were exposed during totality. Details of these exposures are given in the following table:

No. of plate	Exposure	Size	Make	Remarks
1	½ second	14×17 in.	Cramer D. C.[1]	Not backed
2	2 seconds	14×17	Cramer Crown	Backed
3	8 "	25×30	" "	"
4	30 "	25×30	" "	"
5	14 "	25×30	" "	"
6	4 "	25×30	" "	"
7	1 second	14×17	Cramer D. C.[1]	"

The very sensitive plates employed were made expressly for this purpose by the Cramer Company. They were carefully backed, with a

[1] Double-coated. The first plate was purposely left unbacked.

PLATE VIII



GROUP OF PROMINENCES IN SOUTHWEST QUADRANT

PHOTOGRAPHED WITH A TELESCOPE OF 6 INCHES APERTURE AND 6½ FEET FOCAL LENGTH BY E. E. BARNARD AND G. W. RITCHEY

solution of caramel and burnt sienna in a little alcohol, by Professor Barnard the night before the eclipse and mounted in the carrier. The backing used, which Professor Barnard had adopted after a series of careful experiments, would not dry rapidly in the moist climate of Wadesboro, and had to be protected with pieces of soft paper covering the backs of the plates, which served the purpose perfectly.

The exposures were made with a wooden shutter, which could be moved across in front of the lens by cords leading into the photographic house. Mr. Ritchey stood at the carrier and moved the successive plates into position for exposure. At the signal from him the exposure was made by Professor Barnard, the proper interval being counted from a telegraph sounder beating seconds in the room.

The previously arranged program was successfully carried out. From the adjoining camp of the Smithsonian party the signals at the beginning of totality and 10 seconds before the close were struck on a bell which could be plainly heard in the photographic house. At the first of these signals the exposures were immediately begun. At the last signal preparations were being made for the last exposure, and when the image was seen on the plate the Sun had just made its appearance, though the interval from the signal could hardly have exceeded four seconds.

The plates were developed at the Yerkes Observatory by Professor Barnard with pyro developer, which he had found to give softer and more transparent negatives than any other developer tried. The resulting negatives offer abundant evidence of the advantage of long focus objectives for photographing the details of the corona. The greatest extension of the equatorial corona is about 40′ from the center of the Moon. The whole of the inner corona is well shown, but to bring out extensions of a degree or more would have required an exposure of not less than a minute. The polar fans are shown with remarkable beauty on these plates, and the inner corona is full of detail. In the area covered ($1^{\circ}.9 \times 2^{\circ}.2$, the longer direction parallel to the equator and the Sun central), four fixed stars are clearly shown, both on the 14-second and 30-second exposures, while at least two appear on the 8-second exposure. These stars are:

DM. +21°642	4.3 magnitude
+21 643	6.0
+21 647	6.5
+20 751	6.2

It would thus appear probable that no intra-mercurial planet, photographically as bright as the 6.5 magnitude, was in the region covered by the plates at the time of the eclipse.

A discussion of certain important facts brought out in these large photographs of the corona will be published hereafter. Briefly, however, it may be said that there seems to be no very striking connection between the prominences and the coronal details, such as was suggested by the photographs of the Indian eclipse of 1898.

The other instruments used included a 6-inch and a 3¼-inch portrait lens, carried on an equatorial mounting kindly loaned by Professor Comstock of the Washburn Observatory. Three exposures each, of 15 seconds, 30 seconds, and 12 seconds, were made by two gentlemen who kindly volunteered their services, but as the driving-clock did not perform well the image of the corona drifted during the exposures.

Two cameras fixed rigidly to a post, a 4½-inch portrait lens by Brashear and a Voigtländer lens of 4 inches aperture and 8 inches focus, were exposed for 1 second, 2 seconds, and 4 seconds by Mr. Wolff, janitor of the Yerkes Observatory. The Brashear lens gave excellent results, the corona being carried three fourths of the distance to *Mercury* with a single second exposure. The negatives made with the Voigtländer lens are less successful, but the rapidity of the lens is attested by the fact that *Mercury* gave a reversed image with 1 or 2 seconds exposure.

Several photographs of the corona were also secured with smaller lenses, but in no case do the streamers extend more than about three fourths of the distance to *Mercury*. As the images are too small for successful reproduction, Mr. P. R. Calvert has very kindly made an excellent drawing (Plate I) combining the different pictures made with the small instruments with some details supplied from the larger photographs. In this drawing the coronal streamers have not been carried as far out as they can be traced on the small pictures.

Professor Barnard states that a glance at the corona projected on the plates in the coelostat house showed at once that it was almost a duplicate of the corona of January 1, 1889, and the images on the small plates fully confirm this impression. It is evident that this form is characteristic of the period of Sun-spot minimum. The prong-like projection to the east, the wide flaring streamers to the west, and the beautiful polar fans form almost a duplicate of the corona of 1889.

SPECTROSCOPIC RESULTS.

The following slitless spectrographs, supplied with light from the coelostat, after a second reflection, were used by Professor Frost, who was assisted in making the exposures by Dr. George S. Isham:

1. A train of three prisms of very white flint glass (from the new stellar spectrograph), 2¼ inches high, curtate face for 2 inches aperture, set at minimum deviation for $\lambda 4227$, with total deviation of 182° 30′. The resolving power of the train for this region is about 100,000. Photographic camera objective of 3¼ inches aperture and 42 inches focus. Cramer Crown plates.

The plate-holder was one belonging to the solar spectroscope, and could be moved in a direction perpendicular to the length of the spectrum, so that several exposures could be made on one plate, avoiding loss of time in changing plates. Thus the spectra of the cusp, of the first flash, and of the corona were taken on one plate, and those of the second flash and of the cusp after totality on the second. The plates were cut during development, so that development of the coronal exposure could be pushed further than for the other exposures.

Exposures: Cusp, 15 seconds before totality (½ second), first flash (2 seconds), corona (30 seconds), second flash (about 2 seconds); cusp, 10 seconds after totality (½ second).

2. Concave grating of 60 inches radius; ruled surface ⅞ × 1¾ inches, 14,438 lines per inch. $\lambda 4600$ (first order) at middle of plate. Cramer Crown plates. Used direct, without slit or image lens.

Exposures: First flash and second flash, each intended to be of about 2 seconds.

3. Plane grating of 2½ inches surface, 14,438 lines per inch, second order, set for the yellow region. Objective of 2 inches aperture and 20 inches focus. Used by Professor Frost for visual observations of the flash, to give the signal for other spectroscopic exposures.

At 45 seconds before totality the dark lines were very sharply defined in the quite limited field of view of the eyepiece. The bright helium line D_3, showing prominences, was seen perhaps 10 seconds before totality, and other lines appeared in succession as totality approached. There was, however, no such multitude of lines reversed as had been expected by the observer, some fifteen or twenty lines being visible when the observer gave the signal for exposing the objective-prisms and concave grating, and himself made the exposure for the red portion of the spectrum.

4. Plane grating of 5 inches ruled surface, 20,000 lines per inch, used in first order, in front of a visually corrected lens of 3½ inches aperture and 42 inches focus, for photographing cusp and flash spectra in the red portions of the spectrum with Erythro plates. A rather too thick color screen of red glass was inserted for cutting off the overlapping violet of the next order.

Exposures: First flash (about 5 seconds), corona (55 seconds), second flash (7 seconds), cusp after totality (½ second).

First flash.—On the photograph taken with the prism train 70 bright lines have been measured between $\lambda 4070$ and $\lambda 4340$. No dark lines are shown on the plate. The concave grating negative shows about 70 measurable bright lines between $H\beta$ and $H\delta$, and no dark lines.

Second flash.—On the photograph taken with the prism train 266 bright lines have been measured between $\lambda 4026$ and $\lambda 4381$ (Fig. 1, Plate IX). Some dark lines are visible, especially at the violet end of the plate. The bright lines are there found to be at the violet edges of the dark lines.

In attempting to determine the identification of the lines from Rowland's list of wave-lengths the following points are noted:

There is a marked dissimilarity from the solar spectrum, particularly in regard to the intensities.

A large number of the identifications which appear most probable are found to be with lines designated in Rowland's list as *N*, or *N d?*; that is, with lines which are nebulous or are difficult doubles. Professor Frost suggests that the nebulous character of these dark lines may be due to the superposition of the chromospheric light, and that the duplicity may possibly be on account of a reversal at the center of the dark line.

Aside from the lines of hydrogen and helium, the identification seems to be certain for numerous lines of iron, titanium, chromium, and several of calcium, strontium, vanadium, and zirconium. High level and low level lines can be to some extent differentiated by the length of the bright arcs.

The concave grating negative of the second flash shows about 150 lines, 110 between $H\gamma$ and $H\delta$ in sharp focus. The bright lines generally seem to be on the violet side of the dark lines, with some exceptions.

Cusp at first contact.—The negative taken with the prism train shows a small number of bright lines superposed upon the strong solar

PLATE IX

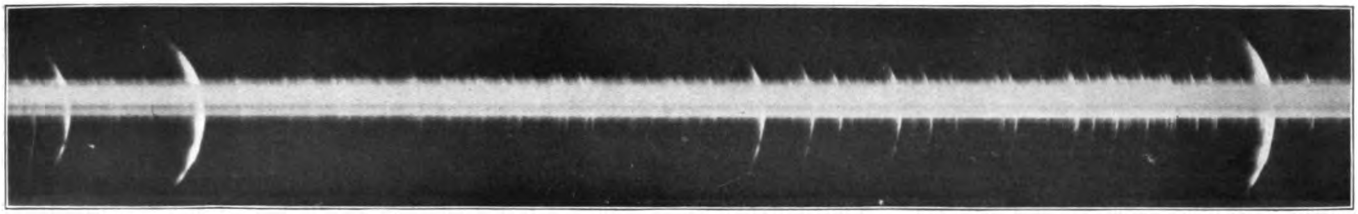
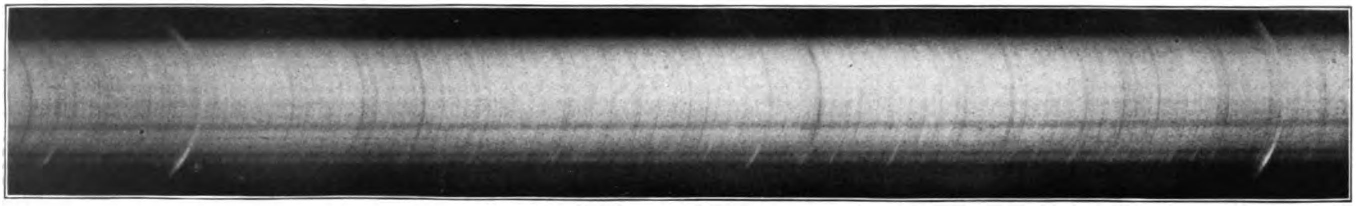


FIG. 1.—THE FLASH AT THIRD CONTACT



$H\delta$ $H\gamma$

FIG. 2.—THE CUSP TEN SECONDS AFTER TOTALITY

SPECTRA PHOTOGRAPHED WITH OBJECTIVE-PRISM TRAIN BY E. B. FROST

spectrum. Several strong lines near the middle of the plate indicate that the bright lines are on the violet side of dark lines. At the ends of the plate, however, the displacement would appear to be in the other direction, at least in the case of several lines.

Cusp at second contact.— About 250 bright lines between λ 4058 and λ 4375 have been measured in this cusp spectrum taken with the prism train (Fig. 2, Plate IX). Many of the bright lines appear to fall on the violet edge of the dark lines. Direct comparison of bright and dark lines shows marked dissimilarity between them.

Corona.— The plate exposed for the coronal spectrum with the prism train shows an intense continuous spectrum, and parts or the whole of seven rings, the wave-lengths corresponding to which are: λ 4078 (chromospheric), $H\delta$, λ 4216 (chromospheric), λ 4230 (coronal), λ 4311 (probably chromospheric), $H\gamma$, and λ 4358 (perhaps coronal).

The exposures on the red portion of the spectrum, with plane grating, were insufficient, partly on account of the absorption of the color screen and partly on account of the less degree of sensitiveness of plates for these wave-lengths. The cusp spectrum shows a few dark and bright lines.

HEAT RADIATION OF THE CORONA.

Through the kindness of Secretary Langley the bolometric apparatus, with which the writer, assisted by Mr. Ellerman, intended to measure the heat radiation from the bright and dark parts of the corona, was used in conjunction with an 18-inch coelostat mirror mounted on the large siderostat of the Smithsonian party. The image of the corona was formed by a 20-inch silvered concave mirror, of 27 feet focus, made in the optical shop of the Yerkes Observatory by Mr. Ritchey. In the cardboard disk on which the image fell was a radial slit, 10 mm long and 1 mm wide, which could be rotated in position angle so as to receive radiations from any part of the inner corona. By means of a suitable combination of mirrors an image of the slit, formed on the fixed bolometer strip by a quartz lens placed beyond the principal focus of the concave mirror, was automatically kept from rotating when the disk revolved. The bolometer, which had to be made in Wadesboro a few days before the eclipse (on account of a serious change in resistance of the old bolometers while in transit from Williams Bay), was 10 mm long and 1 mm wide. The very sensitive galvanometer (figure of merit about 3×10^{-10}) was one made by Professor C. E. Mendenhall, who kindly loaned it for this occasion.

With a period of 5 seconds, and a battery current of 0.3 amperes through the bolometer, this apparatus gave a deflection of about 20 mm for a candle at a distance of 3 m from the bolometer strip with no lens or mirror interposed.

The apparatus was in perfect adjustment just before totality, but at the critical moment an accident disturbed the balance of the bolometer circuit, and sent the spot of light off the scale. The work of rebalancing the circuit was completed during the total phase, but just as the signal was given to expose the Sun reappeared. During the succeeding partial phase a large number of measures were made of the heat radiation of the sky near the Sun. Like many similar measures made at Williams Bay in previous years, they show no certain difference between the radiation of corona plus sky and sky alone. Fortunately Mr. Abbot's measures of the heat radiation of the corona explain this, and as they also answer the question which had led to our own eclipse work, its failure is of less consequence. The deflection which he obtained from the corona (as compared with the dark Moon) was very small—much smaller than had been anticipated. The bolometric apparatus used in our work at Wadesboro, as well as that of previous experiments, was rather more sensitive than that employed by Mr. Abbot, but the angular aperture of our concave mirror, and consequently the intensity of the (larger) solar image, has always been much less than his. Thus in our observations the difference between corona plus sky and sky alone has never been great enough to be detected. Further experiments, made in the hope of measuring in full sunlight the position angle of the edges of the great coronal streamers with an extremely sensitive radiometer, are now in progress at the Yerkes Observatory.

Arrangements had been made to photograph the chromosphere and prominences at the Yerkes Observatory at the time of the eclipse with the spectroheliograph attached to the 40-inch telescope, but clouds prevented.

ACKNOWLEDGMENTS.

It is a pleasure to be permitted to express our sincere thanks to all who contributed to the success of the expedition. We are indebted to the mayor and citizens of Wadesboro, who made every possible provision for our comfort and welfare during our stay in North Carolina;

to Mr. John Leak, for the free use of the land on which our instruments were erected; to Secretary Langley, for the use of the large Smithsonian coelostat, and for many other courtesies; to Mr. O. W. Potter, Mrs. H. M. Wilmarth, Mrs. George Sturges, Mr. Samuel Allerton, Mr. J. H. Moore, and Mr. M. A. Ryerson, for contributions to the eclipse fund; to Dr. George S. Isham, who not only contributed to the fund, but accompanied the party and gave most valuable assistance in the work of preparation and on the day of the eclipse; to the officials of the Chicago & Northwestern Railway Co., and particularly to General Traffic Manager H. R. McCullough, who furnished free transportation for the members of the party and their instruments over the line of this company, and assisted us in other ways; to Mr. C. G. Abbot and other members of the Smithsonian party, whose aid and advice were of great value; to Professor C. E. Mendenhall, for the use of an excellent galvanometer, set up and adjusted by himself; to the U. S. Weather Bureau, for daily weather bulletins; to Professor Flint, Professor Goodwin, Professor Laws, Professor Noyes, and other gentlemen who kindly volunteered their services; to Mr. P. R. Calvert, for the beautiful drawing of the corona reproduced in Plate I; to Mr. S. C. Reese, Mr. S. B. Barrett, and Mr. C. E. Rood, for solar observations made at the Yerkes Observatory during the absence of the eclipse party; to Professor George C. Comstock, Mr. J. A. Brashear, Mr. William Gaertner, Mr. O. L. Petitdidier, and the Vanderbilt University, for the use of instruments; to the Chicago Color Photo Co., for a supply of Erythro plates; to Mr. William Braisington, building contractor at Wadesboro, who not only erected our buildings in a very satisfactory manner, but rendered much additional assistance without compensation; and to many others whose aid was hardly less important. It is proper to add that the results briefly referred to in this *Bulletin* are primarily due to the energy and enthusiasm with which each member of our party performed the task entrusted to him.

George E. Hale.

July 23, 1900.

OBSERVATIONS OF THE TOTAL ECLIPSE AT CENTREVILLE, NORFOLK CO., VA.

The observers from Brown University, Providence, who were joined by several from Boston, located at Centreville, twelve miles south of Norfolk, Va. The approximate position of the station is long. 76° 11′, lat. 36° 41′. Transit and zenith telescope observations for more exact position were made.

The equipment consisted of two 4-inch visual telescopes, one of which (a Brashear lens) was reduced to a 3-inch and used for a photographic telescope; an equatorial stand driven by clockwork, upon which the Brashear telescope was placed and also a 3-inch Clark lens with focal length 135 inches and a 3-inch Allen lens with focal length 77 inches; a prismatic camera with flint prism of 60° in front of a 2.5-inch telescope with focal length 38 inches; four cameras with apertures ⅞ inch to 3 inches and focal lengths 6.5 to 22 inches.

The chief observations planned were visual observations of the times of contact and a special study of the coronal region near some conspicuous prominence; photographic observations of the solar crescent during partial phases, and of the corona especially for its extensions, search for possible intra-mercurial planets.

The contacts were observed by W. Upton and W. S. Meader. The duration of totality was observed to be 99 seconds, instead of 101 or 105 seconds as calculated for the approximate position of the station by the tables of the American and English Almanacs respectively. The second contact preceded the calculated time by three seconds.

The visual study of the corona in the vicinity of a prominence was made by W. Upton with a 4-inch telescope, power 60. Attention was confined entirely to the great prominence in the southwest quadrant. A very careful scrutiny of the corona showed no trace whatever of any hood or distortion of the corona in its vicinity. The structure was radial and there were several folds one upon the other at a distance half a diameter and greater from the Sun's limb, very much as represented in the combined photograph of the 1878 eclipse published by the United States Naval Observatory. The polar streamers and the equatorial extensions of the corona were casually noted, and the corona resembled in general that of 1878 observed at Denver with a telescope of 5 inches aperture.

The equatorial stand was in charge of J. Edwards. With the 4-inch Brashear telescope, fifteen successful exposures were made during the first partial phase and twelve in the second partial phase. These were made with a rapid moving drop shutter containing a narrow slit. The negatives show sharp outlines for the crescent, and can be used for determining the relative position of Sun and Moon. Ten of the plates in each series are at exactly corresponding times before and after totality. During totality six exposures were made in the corona with times varying from 1 to 20 seconds. The best detail is shown on

the plates with times 5 and 8 seconds, both of which were made on Seed's orthochromatic plate. The other plates were special triple-coated plates made by Seed. All plates were backed with Bostwick's anti-halo. Immediately after totality seven exposures were made from ½ to 4 seconds, and extending to 50 seconds after third contact. All show the coronal outline which could have been photographed longer. This apparatus was in charge of H. D. Kenyon, assisted by E. A. Kenyon.

The long focus lenses on the equatorial stand were used upon a region extending 13° west and 18° east of the Sun along the line of its equator. Four 8 × 10 plates were placed side by side in the holder adapted to the Clark lens and three in that of the Allen lens (which has the shorter focus). The width of the belt photographed was 4° for the former and 7° for the latter lens. The proper curvature for each lens was determined by experiment. The plates were Seed 27. An exposure of 60 seconds was given the Clark and 20 the Allen lens, and a supplementary exposure of 15 seconds was given each. None of the plates were fogged by excessive exposure and all have been successfully developed. The images drifted somewhat, giving trails instead of dots. Mercury is prominent and there is much detail in the coronal images, but no stars have been found in the first examination. These cameras were managed by J. Edwards, assisted by N. B. Whitaker, and by Messrs. T. Sawyer, F. L. Lilley, W. K. Wood, D. W. Wood, and W. W. Cooper, of Centreville.

The prismatic camera was managed by F. Slocum, the exposures made upon an Eastman film in a roll holder. Several quick exposures were made before and after totality, one each at the times of second and third contact, and three during totality of 15, 35 and 10 seconds respectively. Many lines are upon the plates, both dark and reversed, and the chief chromospheric lines are prominent. A faint continuous spectrum was obtained during totality.

The smaller cameras were in charge of H. P. Abbott, O. B. Cole, Mrs. Cole, Mrs. Slocum, and S. M. Wright, of Centreville. Six exposures were made with a Darlot lens of 22 inches focal length, $\frac{f}{a} = 16$, with times from 3 to 20 seconds; four each with a Darlot and a Dallmeyer lens of 12½ inches focal length, $\frac{f}{a} = 8.3$ with times 10 to 20 seconds, equivalent to 33 to 66 for $\frac{f}{a} = 15$; three with a small

camera of 6½ inches focal length, $\frac{f}{a} = 7.4$ with times 8 to 30 seconds, equivalent to 33 to 120 seconds. Many of these plates are excellent, showing extensions out to 3 diameters from the Sun. The eastern wing of the corona shows one or two subsidiary extensions in addition to the chief projection, and the first tail on the west has several projections between the two marking its northern and southern boundaries.

Meteorological observations were made by O. B. Cole and the shadow bands were noted by J. Ritchie, Jr., and E. F. Sawyer. An attempt to photograph the bands was made by Miss M. F. Babcock. The temperature fell 8° and recovered somewhat slowly. The wind was very light and veered gradually from S.E. to S. There was little evidence of any fluctuation ascribable to the eclipse. The shadow bands were seen two minutes before and after totality and their forms and directions carefully marked upon white sheets placed on the ground. They were very faint, about an inch in width and with a space of an inch between them. They had an irregular convex front and moved with a quivering, unsteady motion. Before totality they moved towards N.E. by E., and after totality towards E.N.E. Their velocity was estimated to be five to ten feet per second.

The time was called each 10 seconds by R. K. Hyde, who also recorded the times of the contacts and of exposures. A metronome marked seconds. No hitch occurred in carrying out the program planned.

The members of the expedition were hospitably accommodated by Dr. W. Keeling Wood, of Centreville. The Western Union Telegraph Company, the Norfolk and Southern Railroad, and the Merchants' and Miners' Transportation Company were especially attentive to the needs of the expedition. The weather was perfect. A heavy dew had fallen the night previous, but none was noted during the eclipse. The sky was cloudless and there was almost no wind.

WINSLOW UPTON.

OBSERVATIONS AT JULIETTE, GA.

THE station occupied by our party—Juliette, Ga.—is on the Southern Railway between Macon and Atlanta, being about twenty-three miles northwest of Macon. Its approximate latitude and longitude are 33° 6′ N. and 83° 48′ W. of Greenwich.

The party consisted of the writer, in charge, Professors W. H. Kilpatrick and W. E. Godfrey, of Mercer University, with several of their students, C. A. Caldwell, Thomas Harrold, Rev. John G. Harrison, O. H. Crockett, Roy W. Crockett, and Mrs. C. W. Crockett. At Juliette we were joined by two amateurs, H. Fritz and H. L. Smith, of Chattanooga, with a 2-inch telescope.

The work was assigned as follows:

The writer with a 3½-inch equatorial, and Professor Kilpatrick with a 4-inch, were to note the times of contact and to make drawings, if possible, each of half the inner corona.

Professor Godfrey, P. J. Christopher, and J. B. Henson were to watch the timepiece.

Messrs. Caldwell, Harrold, Christopher, and Godfrey were to draw each one quadrant of the corona, as seen with the naked eye.

Messrs. Fritz and Smith were to note the times of contact and to make sketches each of half the corona.

Mrs. C. W. Crockett was to make a drawing of the entire corona, as seen with the naked eye.

O. H. and Roy W. Crockett were to observe the shadow bands.

Rev. Mr. Harrison was to note the temperature.

The sky was cloudless and the observations satisfactory. The reports have not been collected, but some of the results are given below.

1. *The times of contact.*—The times noted by Professor Kilpatrick and myself agreed within a second for the first two contacts; the third contact he failed to get, studying as he was the other limb of the Sun; in the last contact his records showed a time later by perhaps twenty seconds than mine. My eyes were fatigued by the strain, as I commenced looking earlier than was necessary; otherwise I know of no reason that would lead me to doubt my recorded time. We also noted the time when the Moon's eastern limb bisected the spot at the vertex of the angle formed by the Sun-spots. My results were as follows:

	Watch times	Correction	90th meridian times
	h m s	m s	h m s
First contact	6 35 01	—3 8.9	6 31 52.1
Bisection of spot	6 56 42	—3 9.0	6 53 33.0
Second contact	7 41 59	—3 9.4	7 38 49.6
Third contact	7 43 17	—3 9.4	7 40 7.6
Fourth contact	8 59 30	—3 10.0	8 56 20.0

2. *Shadow bands.*—A sheet was spread horizontally, the corners being tacked to stakes driven in the ground. The observers reported that the bands were about the width of a man's hand, wavy and indistinct, and that it was impossible to count them.

3. *The temperature* fell decidedly during the eclipse, the fall during totality being about a degree Fahrenheit.

4. *Inner corona.*—Two interesting features on the western half of the Sun's limb were noted by me — using a 3½-inch glass with a power of about 40. One was the polar radiating streamers, the other a petal shaped formation about 90° from the solar vertex. In my drawing a prominence is shown at the center of the base of the petal; the petal itself was brightest at its boundaries, but otherwise, so far as I noted, it was without peculiarities.

5. *Brightness.*— I have been accustomed to observing the Moon with the same telescope and eyepiece, and in my judgment the intensity of the light from the inner corona is less than that from the Moon.

6. *Outer corona.*—A sketch was made by Mrs. C. W. Crockett, and the members of the party expressed themselves as considering it a good representation of the corona as it appeared to them.

7. *Mercury* was seen. Some one of the party said that another heavenly body was visible, and I am seeking more definite information.

C. W. CROCKETT.

RENSSELAER POLYTECHNIC INSTITUTE,
July 2, 1900.

OBSERVATIONS OF THE TOTAL SOLAR ECLIPSE OF MAY 28, 1900, BY THE HARVARD OBSERVATORY EXPEDITION.

THE plans of the Harvard Observatory Expedition involved (*a*) the search for an intra-mercurial planet; (*b*) the securing of some satisfactory photographs of the inner corona; (*c*) the securing of photographs of the outer corona; (*d*) actinic measures of the brightness of the corona, sky, and Moon; (*e*) shadow band observations; and (*f*) visual measures of the minimum size of the polar filaments.

The intra-mercurial apparatus was of considerable mass and bulk, measuring in general $6 \times 6 \times 11$ feet, and together with the telescopes for photographing the inner corona, and two of the actinometers, was carried on a mounting formerly used to support the Clark 12-inch telescope. The other instruments were mounted separately, without

clockwork. There were in all nineteen cameras, one 4-inch and one 5-inch visual telescope. As I had only one assistant from the Observatory, Mr. W. H. Attwill, available for photographic work, it was necessary to employ native help. At previous eclipses this plan had worked very well, but in the present instance it proved unfortunate, for although every one had been carefully instructed on no account to touch the telescope while the exposure was being made, yet a native assistant becoming excited changed a plate-holder almost at the very beginning of the exposure, so jarring the instrument that all the plates taken with it were a total failure.

Our photographs obtained with the other instruments of the outer corona proved very successful, as did those taken for the purpose of determining its brightness. These have not as yet been measured. No results can therefore be given until they have been reduced, but it may be said that they fully confirm the general impression derived from visual observations that this eclipse was an unusually bright one.

Mr. J. R. Edmands recorded the time of appearance of the shadow of the Moon upon the sky, and of other shadow bands upon the screen, before second contact, and observed the time of disappearance of the bands after third contact. He noted that they were spaced about four inches apart, or nine to the yard; also that they had length, but no describable shape or curvature. He observed also the time of fourth contact.

It seemed to the writer to be a matter of general importance to determine if the photographs showed all the visual detail that there was in the corona, or if, as in the case of the Moon and planets, still finer detail existed which our present photographic appliances were unable to portray. This seemed the more important since very delicate visual detail had been reported at the eclipse of 1878. A ½-inch eyepiece was therefore prepared, furnished with two cross wires, one of silk and one of glass, subtending angles, as seen in the telescope, of 1″ and 6″ respectively. After a careful examination of the polar filaments only one could be found that was as fine as 6″ in diameter, although the definition was such that, had any existed subtending as small an angle as 1″, it would certainly have been detected. My conclusion, therefore, is that the better class of photographs should show all the fine detail that can be seen with our present visual appliances. I observed also the times of first and fourth contacts.

WILLIAM H. PICKERING.

HARVARD OBSERVATORY,
Cambridge, Mass., June 30, 1900.

OBSERVATIONS OF THE TOTAL ECLIPSE BY THE VASSAR COLLEGE PARTY.

The two observers of the eclipse from Vassar College selected Wadesboro as their station and were situated on Carr's Hill an elevation outside the town limits. A 3-inch Clark telescope and a pair of 2-inch field glasses with a direct vision spectroscope attached to one eyepiece were the instruments used. The observations planned for were (4) and (7) of the Eclipse Committee Circular of March 29, *i. e.* color of prominences and distribution of coronium. Miss Furness, who observed the prominences is familiar with the appearance of the prominence as seen in the spectroscope. The eyepiece of telescope was provided with cross-wires for location in position angle, and these were oriented during partial eclipse by the motion of a Sun-spot. The power was sufficiently low to allow the whole rim of the Moon to be seen. No white prominences were observed, but all were of the usual rose color with one exception. A triangular-shaped prominence about the middle of the S. E. quadrant appeared to be somewhat more pinkish than the others.

The direct vision spectroscope attached to the field glass was a McClean star spectroscope with the cylindrical lens removed. The apparatus was tested as suggested in Professor Hale's article in the January number of the Astrophysical Journal. The observation during totality was, however, without satisfactory result. The chromospheric rings with the larger prominences were clearly and beautifully seen in several colors, but the continuous spectrum of the corona was so bright that the green coronium image could not be separated from it. I conclude that the dispersion of the prisms was not sufficient. The inner corona was much brighter than I had expected.

Mary W. Whitney.

OBSERVATIONS BY THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY PARTY.

The Institute of Technology party in Washington, Ga., did not contain any observer who could properly be called an astronomer, and there was no attempt made at original research.

The Institute party first determined the latitude and longitude of the station. (A solid brick and cement pier marks the point.)

Observed latitude, N 33° 43′ 49″
Observed longitude, W $5^h\ 30^m\ 56^s.2$

The four contacts were observed as follows (*mean local time*):

1st contact	- -	7^h	02^m	$22^s.7$
2d "	-	8	09	52 .0
3d "	- -	8	11	18 .2
4th "	-	9	28	26 .9

G. L. HOSMER, Observer.

We tried to do this part of the work as well as possible, and our outfit was quite complete for time and latitude observations.

Six fairly good photographs were taken by Harrison W. Smith with a special camera devised by him, and several fairly complete sketches were made. (Half-tone reproductions of photographs and sketches will be given in the July number of the *Technology Review*.)

Observations were made with the magnetometer on the day of the eclipse to see if any disturbance in declination could be detected. The magnetometer readings showed only the normal daily variation.

The Institute of Technology party made a small plan showing location of station with reference to nearest house and road, observed the dip and declination of magnetic needle and established a meridian line.

ALFRED E. BURTON.

OBSERVATIONS AT WADESBORO, N.C.

THE eclipse was observed at Wadesboro, N. C. A 2-inch and a 3-inch refractor, with powers 9 and 28 respectively, were mounted together upon one axis. The entire period of totality was given to observation, notes and sketches being made after third contact before leaving the observing chair. A very careful search for white prominences in both glasses convinced me that none were present.

I recorded the "impression" that the red prominences were not all of the same shade, and, later, added the note that the red was, in general, lower than at *Ha*. The polar streamers, hurriedly observed, were seen as discrete filaments, symmetrically disposed at each pole, estimated to have a radial altitude of from one fourth to one third of a solar diameter. The equatorial corona was continuous along both limbs, and presented no peculiar variations or curvature save at one point, viz., east and a little north from the *double* prominence that appeared upon the east limb, distant three, or it may be five, times the altitude of the prominence, there was a place where the corona showed

a decided curvature, concave as viewed from the south. The appearance was not that the entire body of the corona was curved at this place, but as though a part nearer the observer was curved, while the main body both around and back of it continued in the same general unbroken manner. This appearance was distinctly noted twice.

On comparative brightness I find only this note: "My impression is that, immediately next to the limb, the equatorial part was not as bright as a little higher up, say up one eighth of Sun's diameter."

When the photosphere (white) reappeared at the west limb, I began to count seconds and watched the corona through the 2-inch *close* at the east limb of the Moon. The bright crescent of the photosphere was approximately in the center of the field. I counted eleven seconds while the corona was still seen immediately at the east limb, the vision being entirely averted once or twice during the count.

The corona at this limb, during perhaps the last four seconds, appeared as discrete spikes and seemed to be lost, not by their fading out, but by the Moon moving on and occulting them.

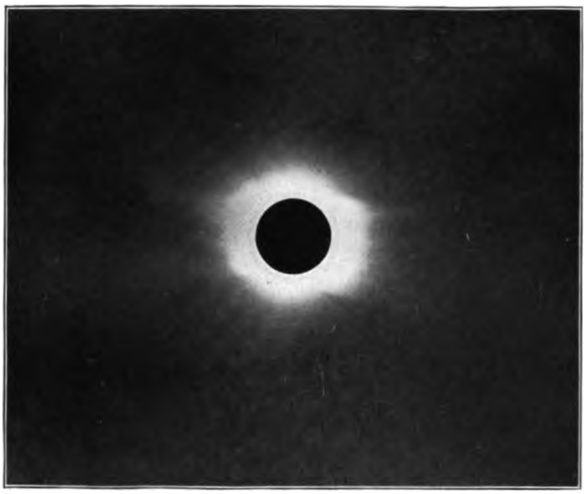
J. B. Coit.

OBSERVATIONS AT SOUTHERN PINES, N. C.

Our eclipse party, which consisted of Mrs. George A. Seagrave, Mr. C. A. R. Lundin, and the writer, occupied a site kindly offered by Mr. J. H. Tilghman, at Southern Pines, N. C.

Mr. Lundin had charge of the photographic work, and used a Clark 4-inch photographic telescope of about five and one half feet focal length, mounted equatorially. The writer took with him two small telescopes, one of three and another of two inches aperture; and a sidereal chronometer, Victor Kullberg 1178. Monday morning was clear and favorable. According to the computations of the writer the first contact would take place at (May 27) $19^h\ 19^m\ 36^s$ Southern Pines local mean time, supposing that $\lambda = + 79^\circ\ 20'$, $\phi = + 35^\circ\ 15'$. At just four minutes before the computed time of first contact I turned the three-inch to the Sun. Mr. Lundin used a two-inch. The seeing was good. As the time drew nearer I drew my attention more closely to the computed position angle of contact, and at $0^h\ 13^m\ 28^s$ by Kullberg I could see the Moon's limb just notching the western limb of the Sun. Mr. Lundin noted it at $0^h\ 13^m\ 28^s.5$. From the time of first contact until totality the writer was busy in observing the gradual

PLATE X



THE CORONA

PHOTOGRAPHED WITH A 4-INCH TELESCOPE BY C. A. R. LUNDIN

advance of the Moon over the Sun's disk with the three-inch telescope. The Sun's surface showed no distortion whatever which could be attributed to a lunar atmosphere. The small spots retained their shape as they were covered by the slowly advancing limb. Mrs. Seagrave, with one or two other observers, saw the shadow bands from three to six minutes before totality. Several white sheets were spread upon the ground, but they were easily seen without them. At three minutes before totality the entire outline of the Moon was visible, and the corona was very brilliant and was composed of many very long streamers. Four very large prominences were seen, and were of a rose color. The corona resembled the one of 1878, and extended from the Sun in the direction of the ecliptic. Mr. Lundin secured six photographs of the corona during totality (Plate X). Each plate was exposed about two seconds. The corona and prominences were visible fully two minutes after totality. The times of the four contacts as observed by me with Kullberg 1178 are as follows:

Providence mean time	Greenwich mean time
$1 = 0^h\ 13^m\ 28^s$	$1 = 0^h\ 36^m\ 50^s$
2 = 1 23 20	2 = 1 46 33
3 = 1 24 56	3 = 1 48 9
4 = 2 44 53.5	4 = 3 7 55

F. E. SEAGRAVE.

THE WEATHER BUREAU OBSERVATIONS OF THE TOTAL ECLIPSE OF MAY 28, 1900.

PROFESSOR WILLIS L. MOORE, as Chief of the Weather Bureau, assigned to Professor F. H. Bigelow the duty of collecting and studying the data showing the probable state of the sky along the path of totality, and several reports on this subject were published, concluding with Weather Bureau *Bulletin* No. 27, "The Probable State of the Sky," etc. The further duty of preparing instructions for meteorological observations to be made during the eclipse was assigned to Professor Bigelow and all the reports received from Weather Bureau observers are now in his hands for discussion and report. He states that there will be between thirty and forty sets of good observations on the shadow bands and from fifty to seventy-five records of special meteorological observations. His report will especially dwell upon the shadow bands and on meteorological matters but will include methods of economically mounting telescopes for photographic work, as illustrated by the

apparatus devised for his own 4-inch refractor. Professor Abbe's report will include sketches of the outer corona by eight or ten different individuals — not Weather Bureau observers. He will also report upon the special observations made by him at Newberry, S. C., on the polarization of blue sky light and on the polarization of the light of the outer corona, as observed by his son, Professor C. Abbe, Jr., of Winthrop College, Rock Hill, S. C. A drawing of both the inner and outer corona made by Professor Very differs entirely from the simple conical sheaf of straight lines of light drawn by Professor Abbe and others, and which outer corona Professor Abbe attributes to streams of illuminated meteoric matter circulating around, or moving past, the Sun. Professor R. A. Fessenden is said to have made some interesting observations on electric disturbances simultaneous with the reappearance of the sunlight.

OBSERVATIONS AT NORFOLK, VA.

My observations were made at Norfolk, Virginia, with a telescope of 4 cm aperture, magnifying 17 diameters. A surprising amount of detail appeared in the corona. The complexity was too great to be fully grasped in the galloping seconds, but I had no difficulty in verifying every kind of structure and form which the best photographs of the eclipses of 1878 and 1889 have shown. The diverging sheaves of polar coronal filaments, ten or twelve at each pole stronger than the others, were distinctly traced through a length of 15′ to 20′ until they merged in a structureless haze which paled gradually into the darkness of the surrounding sky. Strong prominences were seen in the southwest and southeast quadrants, the former (some 4′ high) inclined from the radius towards the south pole, the latter (a little on the east side of the south pole) straight, acutely pointed, and radial; besides several smaller prominences. The chromosphere and prominences stood out in vivid brightness, almost as if with a metallic sheen as of ruddy gold or burnished copper, on the silvery white background of the corona. The equatorial wings were still bright at ½° from the limb, but fading away with that gradual diminution of intensity which is perhaps described by the epithet "pearly," expressing a peculiar translucent quality as applied to luster.

A photograph of 20 seconds' exposure, taken by Professor R. A. Fessenden, shows a narrow, straight ray making an angle of about 40°

with the northernmost of the eastern equatorial wings and 79° from the vertex on the east side, nearly tangent to the Sun's limb in the southeast quadrant. The total distance between the fading extremities is about 2° 12′, the ray being equally brilliant on either side of the corona.

Professor Fessenden, assisted by Mr. A. H. Thiessen, attached a Marconi coherer to a wire stretched from a glass insulator at the end of a 10-foot pole projecting horizontally from a tower at a height of 48 feet above the ground, the wire being carried thence diagonally southeast to the coherer, which was very perfectly grounded. Only momentary clicks were noted during the last half hour before totality, but upon the return of the light, the instrument chattered continuously for 20 or 30 seconds.

Only naked eye observations were made by the other members of our party. Mrs. Fessenden saw the planet *Mercury* but no stars. Through the telescope, the streamers remained visible for 3 or 4 seconds after the end of totality, and the inner corona, with a breadth of 2′ or 3′ of arc, for fully 4 minutes longer.

FRANK W. VERY.

U. S. WEATHER BUREAU STATION,
Rock Point, Charles Co., Md.

OBSERVATIONS BY THE GEORGETOWN COLLEGE PARTY.

THE Georgetown College party, at a station south of Norfolk, Va., confined its program to visual observations with opera glasses and to experiments with two small cameras. The following facts were established :

(1) The light of the corona was strong enough to show the entire disk of the Moon half a minute *after* totality.

(2) The *actinic* power of the two large prominences was very much stronger than that of the planet *Mercury*, although *visually* the latter seemed considerably brighter than the former. The planet was identified by a triple image in the shape of a small triangle, produced by slightly touching the camera twice during a four second's exposure.

(3) The sky remained *brighter* than a full Moon night. This was found from reading different types at given distances.

J. G. HAGEN, S. J.

PERSISTENCE OF THE CORONA AFTER TOTALITY.

The Dickinson College eclipse party took with them a 5-inch equatorial telescope of eighty-six inches focal length for photographing the corona. After developing the pictures taken our negatives show that the corona persists after totality. We were situated at Pungo, Va., very near the central line of totality. The sixth picture taken shows the corona with streamers about one diameter in length, and the inner corona and prominences much over-exposed. The seventh picture shows the corona much less in extent and the crescent of the reappearing Sun. The eighth picture shows the corona all around the Sun and a larger crescent. Now, the *best* time made, *in practice*, in changing plates was ten seconds and usually the time was about twelve seconds. Picture number seven was taken *after* totality was over, and number eight was exposed *at least* ten seconds after that, and probably the exposure was as much as fifteen seconds after the Sun reappeared.

John Fred Mohler.

Dickinson College,
July 2, 1900.

JAMES EDWARD KEELER.

Two years have scarcely elapsed since an announcement appeared in this Journal of James Edward Keeler's appointment as Director of the Lick Observatory. His excellent judgment, high scientific ability, and exceptional breadth of view fully warranted at that time a prediction of success which has already been more than realized. And now, with the task of reorganizing the work of the Lick Observatory admirably achieved, and the Crossley reflector yielding unequaled photographs of star clusters and nebulæ as the direct result of his individual labors, the sad news comes that he passed away on August twelfth. The news was wholly unexpected, for while it was known that he had been suffering from a severe cold, there had been no intimation that any serious outcome was even remotely feared.

Pending the preparation of an adequate account of his life and work I can only add that the loss to astrophysics, to the Lick Observatory, to this Journal, and to many of us personally, will be simply irreparable.

George E. Hale.

THE

ASTROPHYSICAL JOURNAL

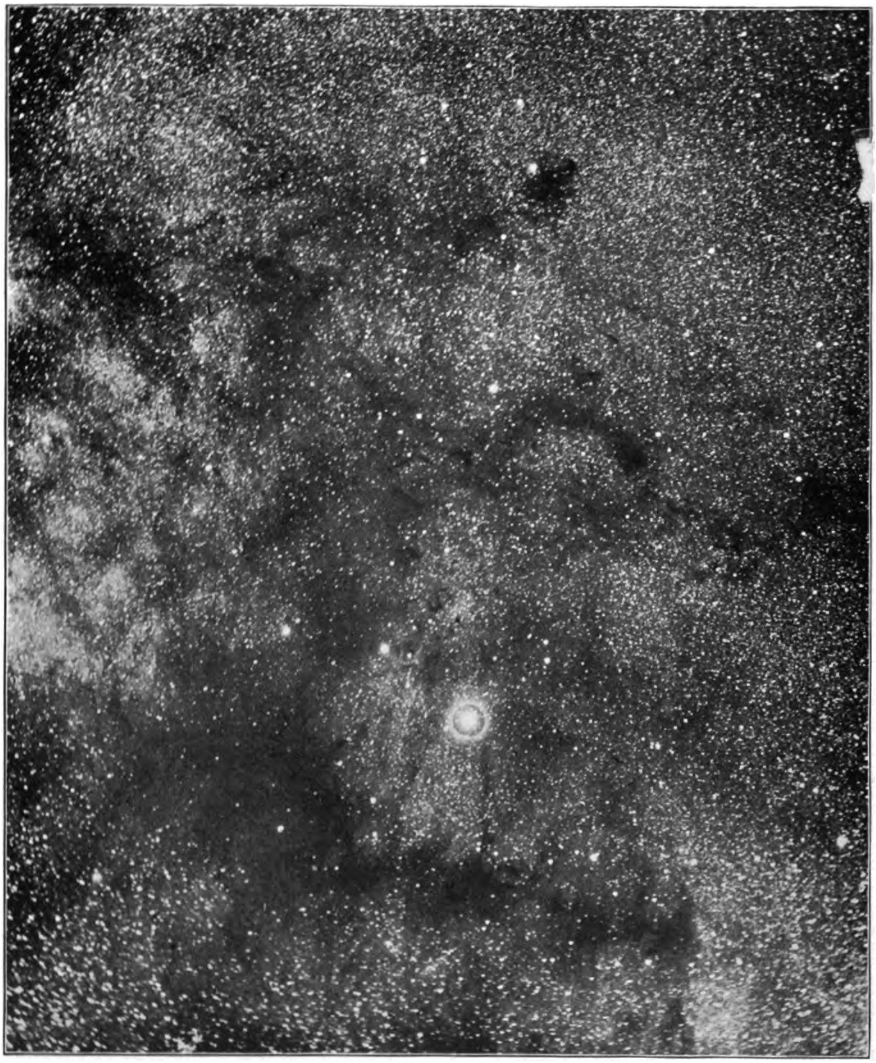
AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOL. XII — SEPTEMBER, 1900 — NO. 2

The ASTROPHYSICAL JOURNAL is published monthly except in February and August. Annual subscription, $4.00; foreign, 18 shillings. *Wm. Wesley & Son, 28 Essex Street, Strand, London,* are sole foreign agents and to them all European subscriptions should be addressed. All papers for publication and correspondence relating to contributions and exchanges should be addressed to *George E. Hale, Yerkes Observatory, Williams Bay, Wisconsin, U. S. A.* All correspondence relating to subscriptions and advertisements should be addressed to *The University of Chicago Press, Chicago, Ill.* All remittances should be made payable to the order of the *University of Chicago.*

[Entered at the Post Office at Chicago, Ill., as second-class mail matter.]

PLATE XI



PHOTOGRAPH OF THE MILKY WAY NEAR THE STAR *THETA OPHIUCHI*

THE
ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME XII SEPTEMBER, 1900 NUMBER 2

THE SPECTRA OF MERCURY.

By WILLIAM B. HUFF.

INTRODUCTION.

THE spectrum of a substance in a vacuum tube assumes different forms as the conditions under which it is observed are made to vary. The discharge through many of the gases has been quite thoroughly studied, as it is affected by temperature and pressure in the tube and by the nature of the discharge.

The fact that mercury is used in most pumps and the great influence which even a very small percentage of its vapor has upon the spectrum of such a gas as hydrogen in a tube, points to the necessity for a detailed study of the mercury spectrum.[1]

Additional weight is added to the above reason by the work of Eder and Valenta, in which they announce their discovery of the band-spectrum and the possibility of breaking this up into a line-spectrum having a vastly greater number of lines than the one formerly known.

Further, since mercury is monatomic, its study should help answer the question as to whether a monatomic substance can

[1] "The effect of certain impurities on the spectra of some gases," E. P. Lewis, this JOURNAL, 10, 1899.

have a band spectrum which can be broken up into one showing lines only.[1]

It may be urged that in the spectrum from a tube, we get the effect of particles thrown off the glass walls and the electrodes, as well as that of the residual gases. Nevertheless, we know that a small amount of mercury vapor in a tube renders the effects due to the presence of some other gases in the tube small.[2]

Accordingly, in studying the discharge through a tube of mercury vapor, we have conditions somewhat less complex than those usually presented when the spectra given by tubes are to be investigated.

APPARATUS.

The gratings used were a large concave one of 21 feet radius and a smaller one of 7 feet.

For obtaining the arc-spectrum, a direct current of about ten amperes was used. The spark and the discharge through tubes were obtained from an ordinary induction coil giving a spark 8 cm long; or from a coil the primary of which carried an alternating current from a Westinghouse dynamo making 130 complete oscillations per second. With no capacity in the secondary, the discharge from this latter coil was an alternating arc. With capacity, it gave a succession of strong sparks. The extreme length of spark obtainable in air was about 2 cm. Shortening the spark increased the rapidity of the succession, as was evident from the pitch of the note given out by the discharge.

For the vacuum tubes, German sodium glass was used. Though Jena glass stood heating better, it was more difficult to seal electrodes into, and at times it would develop longitudinal cracks several days after working and at some distance from a joint. For exhausting, the ordinary forms of mercury pump were used, with drying apparatus, etc. Pressures were read with a M'Leod gauge. Except for rough work, tubes were carefully cleaned and mercury was freshly distilled just before using. It was found that repeated sparking always raised the pressure of a tube joined to the pump. This was true, even when the sparking

[1] LOCKYER, *Proc. Roy. Soc.*, **21**, 1873. [2] LEWIS, *loc. cit.*

and exhausting were repeated at intervals for several days. Before sealing off from the pump, the mercury in the tube was boiled and the walls of the tube were heated.

ARC-SPECTRUM OF MERCURY.

Preliminary to a study of the spectra of mercury in tubes, it was deemed advisable to obtain the arc-spectrum. This was attempted by Liveing and Dewar, but they say they found it impossible to get more than comparatively few lines. Of the lines found, but one, $\lambda = 2536.8$, was reversed.

Kayser and Runge,[1] however, seem to have had no difficulty in obtaining many lines from the arc. They give a list of wave-lengths in their papers on the spectra of the elements.

The first attempts to obtain the arc-spectrum of mercury in this investigation met with small success. Carbon poles were used and the lower one was bored out to a depth of about two inches. This positive pole was filled with the sulphide and, in later attempts, with the metal itself. In neither case were more than a few lines obtained, and these were weak compared with those from the poles, even when a small current was used. Only the strong lines given by Kayser and Runge were found. It became clear that enough metal must be supplied so that it could boil off freely from the arc, for sometimes even when the pole was nearly filled, not a single mercury line appeared on the plate.

Finally, a long carbon was bored out and a rubber tube leading to a reservoir was attached to the lower end. This made it possible to keep the mercury at the very top of the pole. The results were satisfactory, a few minutes exposure giving on the plate all the lines found by Kayser and Runge in that region. In the extreme ultra-violet, an exposure of an hour with the large grating gave lines of wave-length as short as $\lambda = 1872$. In this ultra-violet region, the plates show some of the comparatively weak lines as coming from the entire space between the poles; others

[1] KAYSER and RUNGE, "Die Spectren der Elemente." 4 Abschnitt, 1891 *Abhandl. d. König. preuss. Akad. d. Wiss.*

are short on the plate, and seem to have come only from near the carbon terminals.

Some of the extreme ultra-violet lines given by Kayser and Runge were not found. Neither did $\lambda = 3305$, of intensity 6, appear on any plate, although a line at $\lambda = 3342$, to which they give an intensity of but 5, came out strongly.

The following additional arc-lines were noted and their wave-lengths found by measuring with a scale from standard mercury lines as given by Kayser and Runge.

Wave-length in Ångström units	Intensity	Character	Wave-length in Ångström units	Intensity	Character
2640.0	3	Double; very hazy	2194.2	1	
2352.5	2		2189.2	2	
2341.0	1		2186.6	1	
2323.0	1	Hazy	2172.1	1	
2284.2	2		2169.2	1	
2275.5	1		2001.6	1	
2259.2	1	Very hazy	1919.5	1	
2230.1	1		1876.0	2	
2227.9	1		1872.2	2	
2197.7	1				

It is difficult to estimate intensities of lines in this region, since the plates show a great deal of continuous spectrum.

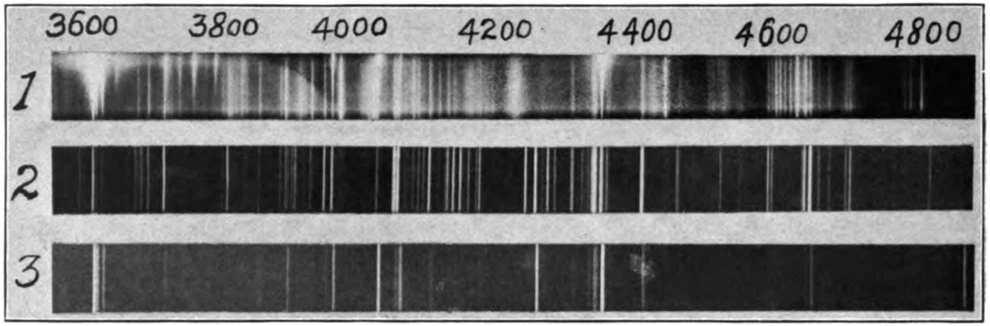
THE SPARK-SPECTRUM.

The study of the spark in air had for its object the investigation of the effects due to changing the conditions of the discharge, and also the determination of the principal air-lines which come out in the spectrum of the spark. A comparison, then, of spark plates with those showing the spectrum from tubes will give an idea of the effect due to the residuum of air in a tube.

EFFECT OF CAPACITY.

Using the large coil, a spark was obtained between an upper terminal of carbon and the mercury held in a broad dish. With no capacity in the secondary, this spark took the appearance of an alternating arc, and the spectrum obtained was that of the arc.

PLATE XII



1. Spectrum of Spark in Air between Platinum and Mercury
2. Spectrum from Tube Sealed off at Pressure of 0.003 mm: small Capacity in the Secondary
3. Same as 2, but Self-Induction in the Secondary

For example, the line $\lambda = 2967$ comes out very strongly in the arc and is given an intensity 10 by Kayser and Runge in their list. It also comes out strongly in the spark when capacity is used in the secondary. To a neighboring line, $\lambda = 2848$, Kayser and Runge give an intensity of 4 in the arc, but in the spark Eder and Valenta find it of intensity 10. With no capacity in the secondary of the discharge from the large coil, $\lambda = 2967$ still comes out strongly as compared with other arc-lines, while $\lambda = 2848$ decreases in intensity to about what it had in the arc.

As the capacity was increased, the hissing discharge became more disruptive in character and the characteristic spark-lines came out; the continuous spectrum also increased, and all the lines became less sharply defined, even when the light was taken from the upper part of the spark, quite away from the surface of the mercury.

The most clear-cut lines were got from the discharge of the small coil before the slit of the large grating, though the exposure was necessarily very long. Using the maximum capacity, the list of spark-lines was found substantially as given by Eder and Valenta.[1]

EFFECT OF SELF-INDUCTION.

The effect of the introduction of self-induction in the secondary was also studied.[2] The inductance coil used consisted of 200 m of copper wire wound in 9 layers of 30 turns each, each turn 6 mm from any other. The self-induction was 0.009 Henry.

Using this coil in the secondary, with capacity, the most noticeable effect on the discharge was the decrease in its violence, owing to the increased period of the oscillations. The general effect on the spectrum lines was to increase their sharpness, the continuous spectrum of the more violent discharge being cut out.

[1] EDER and VALENTA, "Die verschiedenen Spectren des Quecksilbers," Wien, 1894.

[2] HEMSALECH, "Sur les spectres des décharges oscillantes," *Comp. Rend.*, 129, 5, 1899; *J. de Phys.*, Dec., 1899.

With self-induction in the secondary, the following lines which appear in both arc and spark spectra were reduced to their arc intensity.

Wave-length λ	Arc intensity	Spark intensity	Wave-length λ	Arc intensity	Spark intensity
2820	4	10	3562	4	6
2848	4	10	3790	2	8
3390	3	8	3984	4	8
3544	4	6			

Characteristic spark lines like

λ	Intensity
5426	8
5679	8

were cut out entirely. (See Plate XIV, 8.)

The lines

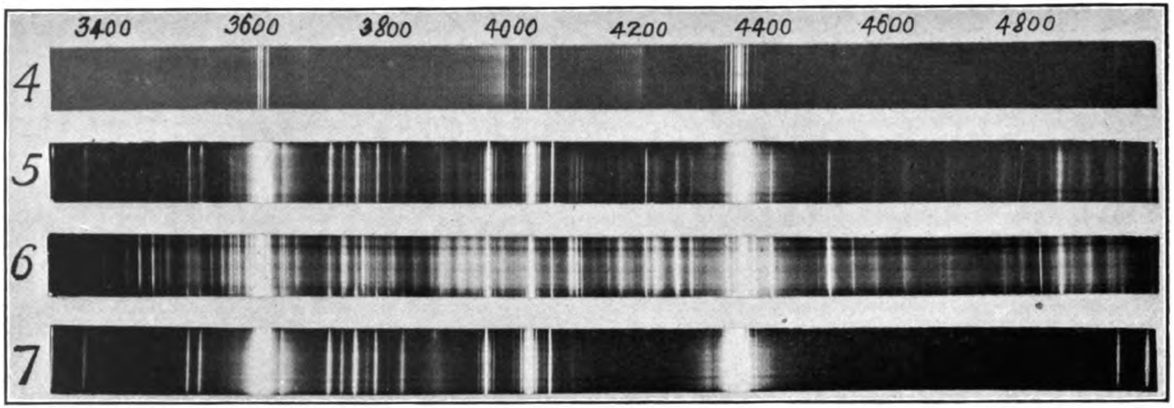
λ	Arc intensity	Spark intensity
5770	10	10
5790	10	10

compared with the line $\lambda = 5461$, whose intensity was 10 in both spark and arc, came out very much stronger for self-induction in the secondary. (Plate XIV, 8.) The effect of self-induction in the secondary is, then, to tend to reduce the spark to the arc and to sharpen the lines. As a result of this sharpening of the lines, $\lambda = 3663$ and $\lambda = 3131$ are found to be double in the spark in air. That the latter phenomenon was not a reversal was seen clearly by comparison with $\lambda = 2536$, where the reversal showed most clearly nearest the mercury terminal. With capacity but no self-induction, a very short exposure shows $\lambda = 3650$ reversed, and exceedingly broad and hazy. The introduction of self-induction brings out a single sharp line. (Plate XIV, 9.)

EFFECT OF LENGTH OF SPARK.

With a given capacity, that of a bank of six one-gallon Leyden jars, a thick spark about 2 cm long could be obtained, very disruptive and giving a note whose pitch was determined by the alternations in the primary of the coil. Shortening the spark raised the pitch of the discharge until, for a length of 3 mm, the

PLATE XIII



PHOTOGRAPHS OF SPECTRUM OF MERCURY IN A TUBE, TO SHOW EFFECTS OF VARYING CAPACITY, AND OF SELF-INDUCTION

4. Band Spectrum. No Capacity Used
5. Capacity One 1-qt. Jar
6. Capacity Two 1-gal. Jars
7. Capacity One 1-qt. Jar and Self-Induction in the Secondary

discharge was a sharp, hissing one, to the ear quite like that when no capacity was used, though in appearance it was still a spark. The spectrum of this short spark gave the arc-lines and some of those due to the spark. The arc-lines $\lambda = 5770$ and $\lambda = 5790$ came out equally well in both long and short sparks, while the characteristic spark lines $\lambda = 5426$ and $\lambda = 5679$ each of intensity 8, came out relatively much stronger in the long than in the short spark.

With self-induction in the secondary, the long and short sparks gave the same lines. It was thought that by comparing the lines obtained from a very long and from a very short spark, a shift might be observed.[1] The very great broadening of the lines in the former case made it impossible to make reliable micrometer settings. The self-induction in the secondary made the lines much less hazy, but also lessened the violence of the discharge.

SPECTRA OF MERCURY IN TUBES.

The best work on the spectra of mercury in tubes is that done by Eder and Valenta.[2] They discovered the band-spectrum given by mercury vapor distilling through a capillary. By using capacity in the secondary of the induction coil, these bands were broken up into an immense number of lines.

A more detailed study of the spectra from tubes containing mercury seemed desirable, including the effect of varying continuously the capacity and the self-induction; also the effect of changing the temperature of the tube and of different forms of discharge.

It seemed well, also, to make direct comparison of plates showing the spectrum of sparks in air with those obtained by the use of tubes whose conditions could be varied. While the coincidence of isolated lines cannot, be accepted as evidence of the effects due to the presence of air in the tube, a group of air-lines appearing on a plate from a tube might be identified with certainty. Some idea would then be obtained of the effect

[1] WILSING, this JOURNAL, 10, 1899.

[2] EDER and VALENTA, "Die verschiedenen Spectren des Quecksilbers," Wien, 1894.

of air as the conditions of the tube were changed. The use of external electrodes would also simplify the conditions.

The first question naturally had to do with the form of tube to be used. The first one tried was similar to that used by Eder and Valenta, and consisted of an ordinary "end-on" tube with about 6 cm of capillary, the light passing through a quartz plate sealed on with liquid glass. But hardened sodium silicate will stand only a moderate temperature and since the work was to be mainly qualitative, it was determined to use "side-on" tubes, although by this the study of the spectra was confined to wave-lengths which glass allowed to pass. A great increase of light came from using a "side-on" tube and since the capillary could be drawn with very thin walls, the shorter wave-lengths were still allowed to pass.

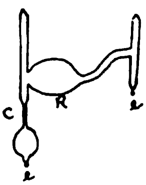


FIG. 1.

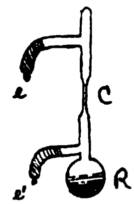


FIG. 2.

The essential feature of the tube must be the possibility of keeping it in a steady state for several hours, if need be. Many forms were made and tried. The spectra obtained could be observed to go through series of changes and could at will be made to repeat these changes. The difficulty was to keep each form constant until it could be photographed. The tubes selected were as shown in Figs. 1 and 2.

The electrodes of platinum are at *e*.

R is a reservoir for mercury.

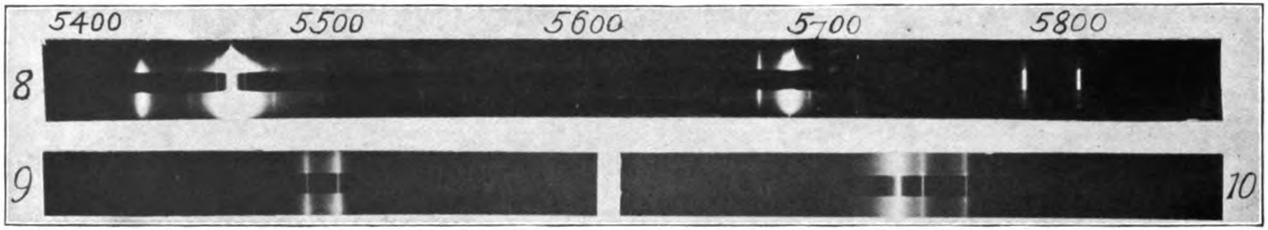
C is the capillary.

By heating the reservoir, the mercury would distil through the capillary. The platinum at the electrodes was covered with mercury.

Upon taking up the study of the tube spectra, it seemed possible that the bands might be due to the glass or to an oxide of mercury formed in the tube.

To free the tubes as far as possible from air, they were kept on the pump for several days and sparked repeatedly. In addition, the mercury was boiled and the whole tube was heated before sealing off.

PLATE XIV



PHOTOGRAPHS SHOWING EFFECT OF SELF-INDUCTION ON SPARK IN AIR

OUTSIDE, CAPACITY BUT NO SELF-INDUCTION
8. INSIDE, CAPACITY AND SELF-INDUCTION
9. SAME AS 8 FOR $\lambda = 3125$
10. SAME AS 8 FOR $\lambda = 3650$

Such a tube containing no glass of internal diameter less than 8 mm was found to show bands where the discharge left the surface of the mercury, both at anode and cathode; and also in the tube at any point between the electrodes. This seemed to make the use of a capillary unobjectionable. Accordingly, a tube of type 1 had its lower electrode filled until the mercury stood in the capillary. The bands were shown strongest from the surface of the liquid, but appeared throughout the tube. This was without other heat than that produced by the discharge from the small coil. At the electrodes, the temperature was perhaps 70° C. The pressure in this second tube had been read 0.1 mm at sealing off. This band-spectrum was identified with that of Eder and Valenta.

Using this same tube, an attempt was made to obtain the line-spectrum of Eder and Valenta by putting capacity in the secondary. To the eye, the only change was that the discharge was not so bright.

Plates including a region between $\lambda = 3000$ and $\lambda = 5400$ showed one band at $\lambda = 4012$ broken up and a few lines to replace it. Capacities were used varying from zero to that of six one-gallon jars, giving no new effect.

The discharge through the tube was made stronger. The tube became hot and a few of the characteristic arc-lines came out strongly, the bands disappearing. Capacity brought out a few new lines. Using a weaker discharge, a small flame under the upper reservoir caused the mercury to distil through the capillary. The introduction of capacity had little effect except after mercury had condensed in the large tube just above the capillary. Until this flowed down, the capillary discharge became a creamy tint instead of green, and showed a spectrum of many lines, for a moment only. It was found that a tube like 2 gave bands, and by heating the reservoir, the light from the distilling mercury of the capillary could be made to give the line-spectrum for any desired length of time.

A tube with a capillary of ¼ mm internal diameter and sealed off at a pressure of 0.01 mm of mercury was slightly

heated, and gave bands which broke up into lines when capacity was used. Too much heat prevented the discharge for a given capacity, as did also too much capacity for a given heating.

With much stronger heating, the discharge would again pass, with a brilliant green color. Capacity made the discharge dazzlingly bright, its spectrum showing continuous spectrum and in addition many lines, some of them considerably broadened. For still stronger heating, the crowd of lines sank back and were merged into the continuous spectrum, only a few of the strongest arc-lines standing out slightly.

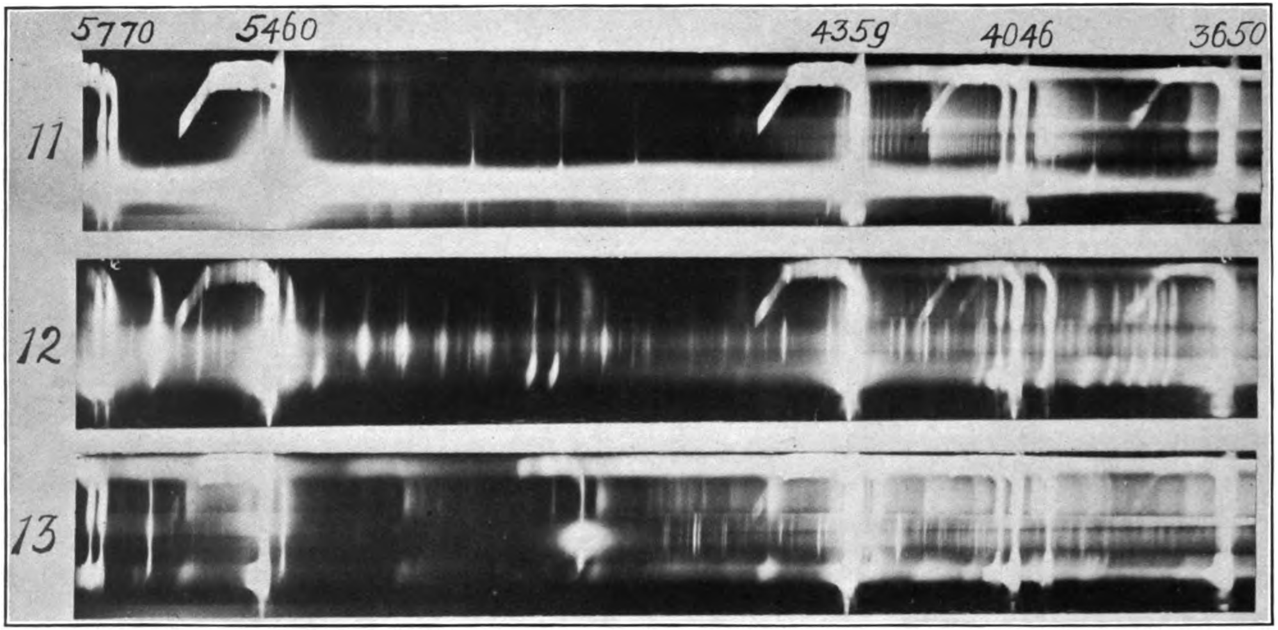
EFFECT OF CAPACITY.

A tube of type 2 sealed off at a pressure of 0.01 mm of mercury was heated with a very small gas-flame held about 10 cm below the reservoir. After several hours of such heating, the spectrum showed lines or bands according as capacity was or was not used in the secondary of the small coil. The conditions were then assumed constant and a series of plates was taken for a capacity varying from zero to the largest that would allow the discharge to pass, viz., that of two one-gallon jars. With a very small capacity, the spectrum was the same as with none, showing the bands. With a one-pint jar in the secondary, the most noticeable change was the appearance of $\lambda = 3984$ and the broadening toward the violet of the group at $\lambda = 3950$. A few new hazy lines appeared in other parts of the spectrum. The line $\lambda = 4216$ came out and the band near it weakened. Using a one-gallon jar and keeping the other conditions constant and the same as for the preceding cases, the bands disappeared entirely, many new lines coming out. With two large jars the effect was but slightly different from that obtained with but one. (See Plate XIII, 4, 5, 6.)

In general, these results show that a gradual increase of capacity in the secondary changes the spectrum from a band to a line-spectrum. The intermediate conditions may be obtained and photographed.

With a too great capacity, of course no discharge passes, but with the maximum which may be used for a given temperature

PLATE XV



SPECTRUM FROM ENTIRE TUBE OF TYPE 2

11. While Strongly Heated and with No Capacity in the Secondary
12. Same, but with Capacity
13. Same as 12, but Less Strongly Heated

and current, there is brought out the maximum number of lines in the series of changes from bands to lines and these lines are of greatest sharpness for the given temperature.

With as wide a range of current difference as could be used through the primary of the small coil, the spectra were essentially the same, the discharge differing only in brightness.

EFFECT OF SELF-INDUCTION.

When the inductance-coil was put in the secondary, with capacity, the discharge through the tube decreased in brightness. The change in the spectrum was analogous to that produced in the case of the spark in air. The principal arc-lines, such as

$$\begin{aligned}\lambda = 3650\\ 3984\\ 4047\\ 4078\\ 4360\end{aligned}$$

were brought out strongly, with considerable continuous spectrum, though in general the lines were sharper than when no coil was used in the secondary. A vast number of lines were cut out entirely, or very much weakened. (See Plate XIII, 7.) For a smaller self-induction, fewer lines were cut out.

By the use of such a coil in the secondary, it seems possible, therefore, to reduce the spectrum obtained by breaking up the bands to one showing only the strongest lines of the arc and of the spark in air.

For the above series of plates, showing the effects of self-induction and of varying capacity, the same tube was used throughout. The conditions were kept as nearly constant as possible, and the observations were extended over a period of fourteen hours. The tube was then allowed to cool, and the spectrum obtained was the same as that before the heating.

PRESSURE.

At comparatively high pressures the principal arc-lines of mercury are given by the spectra of tubes. The bands appear while the tube contains enough nitrogen to obscure everything

else in the ultra-violet. As the pressure is decreased, the amount of heat, in addition to that from the current needed to give the brilliant discharge, grows less, and it is consequently easier to get the most abundant line-spectrum. A small capacity gives these lines, and they persist throughout the capillary. The character of the lines also changes, for while with more heat the lines are hazy and shaded on both sides, though more toward the violet, the lines from tubes heated only by a small current are sharp and clear. (See Plate XII, 2.)

Indeed, this sharp line spectrum would scarcely be recognized as related to that obtained at higher pressures. That it is so related was shown by exposing that part of the tube near where the capillary met the larger tube. From the same exposure the one part of the plate showed bands, the other this sharp line-spectrum.

On slightly heating this tube, the discharge changed from its bluish tint in the capillary to the characteristic brilliant one, and with capacity, this yielded the same spectrum obtained from tubes sealed off at higher pressure and examined when at higher temperature; also the same lines, so far as eye observation could determine, were seen in tubes sealed off at yet higher pressure and studied when still more strongly heated, but not photographed, owing to the difficulty of keeping their condition constant for any length of time.

The pressures at which the above three sets of tubes were sealed off from the pump were given by the gauge at 1 mm, 0.06 mm, and 0.004 mm.

AIR LINES.

Since the presence of even a trace of mercury vapor in a tube is sufficient to show the lines

$$\lambda = \begin{array}{r}5769\\5461\\4358\end{array}$$

and seems also to reduce the intensity of the lines due to a gas like hydrogen, a comparison was made between plates obtained from a tube and those of the spark in air.

A tube was strongly heated, and sparked while on the pump, and was sealed off at a pressure of about 0.003 mm. This tube gave a spectrum of sharp lines. Plates taken with the small grating, using a spark between platinum and mercury, showed short lines due to the electrodes, but air-lines extending entirely across the plate. A comparison of spark-plates with those from tubes showed the following groups of air-lines on both (see Plate XII, 1, 2):

$\lambda = 4070$
4120
4182
4318
4350
4415
4705

Other lines showed coincidences, but only in cases like the above, where an entire group was the same, could it be said that the air-lines persisted in the tube. The above groups were sometimes of scattered lines; in several cases they were of fine, sharp lines, close together and equidistant. In every case the character of the group was such as to make certain its identification on the two sets of plates.

The introduction of an inductance-coil in the secondary either very much weakened or entirely cut out every group noted above. (Plate XII, 3.) When this tube was heated and capacity was used in the secondary, the spectrum given was quite distinct from the one previously obtained with capacity but no heating. If the air affected this second spectrum, it was in a way not easily traced. From tubes sealed off at higher pressure, and which were not heated except by the discharge, the band-spectrum of mercury was obtained, with only traces of the groups of air-lines. The air lines seem, therefore, to come out most strongly at very low pressures and temperatures, but to disappear under conditions giving the bands or the "spectrum of many lines." These air-lines reappear in the spectrum from a tube that has been heated until they disappear, but which is examined when again cool.

The color of the capillary of a tube at a pressure of 1 mm, and not heated, was purple. For a lower pressure, the effect of the nitrogen was lost, and the capillary became pink when the discharge first passed, but soon changed to green. When a tube contained capillaries of different sizes, the pink persisted longest in the finest tubes. For a pressure of a few thousandths of a millimeter, the capillary became blue. But when strongly heated, all tubes showed the characteristic green of the mercury $\lambda = 5461$, and with capacity gave the dazzlingly bright discharge.

STUDY OF THE ENTIRE TUBE.

Using a plane grating as objective, a complete set of plates was taken from the tube used in studying the changes due to varying the capacity. The advantage of thus photographing the entire tube is obvious, since such a plate gives an image of every part of the tube for each wave-length coming from that part. A small grating held in the hand was found much better than the ordinary direct-vision spectroscope for watching the discharge through a tube so that it might be kept constant during an exposure.

To photograph the entire tube, it was set up at a distance of 4 m from a 5½-inch plane grating. The light from the grating was brought to a focus on a plate about 2 m distant by means of a quartz lens. The region thus obtained was from $\lambda = 3200$ to $\lambda = 5800$.

When heated until the brilliant discharge passed, the bands were shown from the capillary and from the large part of the tube between capillary and anode, but not between capillary and cathode, where only a few lines appeared, broad and hazy in the continuous spectrum. With capacity, the line-spectrum appeared, with no trace of bands. In general, the lines persist throughout the tube. One line in the blue comes out in the capillary and on the side toward the anode; two others in the blue come out in the capillary and on the side toward the cathode, as does also one in the green. But few lines continue down to the boiling mercury in the reservoir, those doing so being principally the strong arc-lines.

If the heat is decreased and no capacity used, the discharge becomes less brilliant and bands at about $\lambda = 5570$ and $\lambda = 4850$ appear, which did not come out when more heat was used. On putting capacity into the secondary, the band-spectrum in the capillary gave way to one showing many lines, though in the large tube toward the anode the bands persisted, as they also did, faintly, toward the cathode. (Plate XV.)

The effect of the introduction of self-induction with capacity was to reduce, or to cut out entirely, throughout the tube, many lines brought out by capacity, noticeably in the blue and blue-green.

Tubes with external electrodes were also used. The form was that of Fig. 3. The electrodes were of tin-foil, wrapped tightly around the glass and then wound with wire. The discharge was not nearly so bright as that obtained from tubes whose platinum terminals made direct contact with the mercury in the bulbs. The spectra from tubes of different sizes and of different kinds of glass showed bands. One of these tubes was so small that the path of the discharge in the tube was not more than 4 cm. Before sealing off from the pump, it was very strongly heated. In plates showing bands from these tubes were some lines which are probably due to glass, since they do not come out with tubes of the first kind. Attempts to break up the bands from tubes of type 3 were not successful. Plates from these tubes obtained with the plane grating as objective showed the bands on both sides of a globule of mercury in the capillary. Some lines appear on one side of the capillary and but faintly, or not at all, on the other.

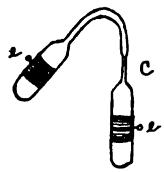


FIG. 3.

ALTERNATING DISCHARGE.

To determine the effect of using the alternating discharge from the large coil, tubes capable of use with large currents were made. With such a discharge, the small capillary was melted at once and one of heavy wall and 1 mm bore showed much continuous spectrum. With a tube of 2 mm inside diameter

the large coil with the bank of six jars in the secondary gave, with $\frac{1}{60}$ the time of exposure, a spectrum essentially the same as that obtained by using the smaller coil. The air-coil with the above discharge gave results similar to those already described. The intense heat developed by the heavy alternating current made it impossible to obtain the bands.

That the resistance of a tube of type 2 to the passage of such a discharge is not only at the electrodes, but also depends on the length of path to be followed, was shown conclusively. The mercury distilling from the electrodes into the reservoir, the length of the path was increased until the discharge would no longer pass. Refilling the arms of the tube from the reservoir, the discharge again passed. The tube was of the same internal diameter throughout.

RESULTS.

The arc-spectrum was obtained substantially as given by Kayser and Runge. A few additional lines in the extreme ultraviolet were noted.

By increase of capacity in the secondary of a coil giving an alternating discharge, the spectrum changed from that of the arc to one containing the characteristic spark-lines. The introduction of self-induction in the secondary of such a coil tends to reduce the spectrum of the spark to that of the arc. A long spark showed lines which were not given by a very short one.

Using a tube, bands were obtained with light directly off the surface of the mercury, both at anode and cathode of a large tube. On heating the tube, the bands disappeared, those in the shortest wave-lengths remaining longest. Capacity breaks up these bands, throughout the tube if it is heated sufficiently; otherwise, only in the capillary and near the cathode where the discharge produces the greatest heating. Self-induction accentuates the arc-lines at the expense of other lines due to very special conditions. By varying the capacity, it was possible to pass continuously from the band to the line spectrum.

For very low pressures, groups of air-lines come out; but are not identified in tubes at higher pressure or in tubes sealed off at low pressure and studied when heated.

The discharge from an ordinary induction coil gave the same spectrum as that from a very strong alternating current.

This investigation was begun at the suggestion of Professor Ames and was carried out under the supervision of the Directors of the Laboratory, Professor Rowland and Professor Ames, whom the writer takes this opportunity of thanking for their assistance, at all times most generously given. Mr. Lewis E. Jewell rendered most valuable assistance throughout the course of the work.

PHYSICAL LABORATORY,
JOHNS HOPKINS UNIVERSITY,
June 1900.

AN INVESTIGATION OF THE ZEEMAN EFFECT,

WITH REFERENCE TO CADMIUM, ZINC, MAGNESIUM, IRON, NICKEL, TITANIUM, CARBON, CALCIUM, ALUMINIUM, SILICON, AND MERCURY.

By HERBERT M. REESE.

THEORY.

WITH few exceptions, all theories advanced so far to account for the Zeeman effect rest on the fundamental ideas of Lorentz[1] or of Larmor,[2] which agree in ascribing to the small particles of matter electric charges which are inseparable from them. Some theories, such as that of Voigt,[3] do not expressly mention charged particles, but introduce into the equations arbitrary terms which are similar to those characteristic of the motion of a charged body.

The simple theory which Lorentz[4] first advanced to account for Zeeman's discovery of the widening of the lines, and which enabled him to predict the doublet and triplet on further resolution, regarded as the source of light a single positively or negatively charged particle, acted upon only by an elastic force toward a position of equilibrium and another force normal to its motion and the magnetic induction, and equal numerically to the continued product of the charge, the velocity, and the resolved part of the magnetic force at right angles to the velocity. Even before the discovery of quadruplets and other complexities, Lorentz[5] began an investigation to determine whether variations from the triplet form were not to be expected. Starting with the idea of a perfectly general molecule, having n degrees of

[1] *Archives Neerlandaises*, Vol. XXV.

[2] *Phil. Trans.*, A, 1895, p. 718; A, 1894, p. 812.

[3] *Wied. Annalen*, No. 2, 1899, p. 345; No. 6, 1899, p. 352; No. 9, 1899, p. 290; No. 2, 1900, pp. 376 and 389.

[4] ZEEMAN, *Phil. Mag.*, March 1897, p. 226.

[5] *Wied. Annalen*, 63, 278, and this JOURNAL, 9, 37.

freedom, he showed that if p of these are equivalent without the magnetic field, the presence of the field will cause the single spectral line corresponding to them to break up into a p-fold group. Lorentz does not regard this explanation of complicated effects as satisfactory, however, owing to the difficulty of conceiving a system having more than three equivalent modes of vibration.

Preston[1] has brought forward, to account for complicated lines, a paper written by Stoney[2] in explanation of those groups of lines in the natural spectra of the elements which make up the so-called series. The suggestions that he makes are purely kinematical. He shows that if we have superimposed upon a motion in an elliptical orbit certain auxiliary motions such as a revolution of the plane of the orbit about a line inclined to it, or a revolution of the apse-lines in the plane of the orbit, the original single period will be replaced by two or more, differing slightly from it. Preston makes no suggestion as to how such auxiliary motions might be brought about physically except in one case. If we regard the vibrating ion as equivalent to a little magnet, the external magnetic force would tend to place the orbital plane perpendicular to the lines of force, and before coming to rest in this position the normal to the plane would make pendulum-like oscillations which would cause a doubling of the central line of the triplet, giving the well-known quadruplet. A single moving ion, however, differs in some essential points from a closed conducting circuit or its equivalent magnet, and it would seem that if any such directive force exists it is fully taken account of in the equations of motion, as given by Lorentz in Zeeman's paper, provided the assumption there made as to the forces acting on the ion are valid. The introduction of the elastic force toward a position of equilibrium seems reasonable, as a central force varying as any power of the distance other than the first would make the period dependent upon the amplitude, which can hardly be the case in light-vibrations; for apparently the position of a line in the spectrum is exactly the

[1] *Phil. Mag.*, 47, 165. [2] *Sci. Trans. Roy. Dub. Soc.*, 4, 563.

same whether it be very intense or quite feeble. Partial justification for making the magnetic effect on the ion equal to that which would act on an element of a conductor carrying a current equal to the product of the charge and velocity of the ion, is found in Professor Rowland's experiment carried out in Berlin in 1876, and repeated by Röntgen, Huchinson, and others, in which a magnet is deflected by rapidly rotating a charged disk. In this case, however, the rotating disk formed a closed circuit, without the interposition of displacement currents in the ether, and such is not the case with an isolated charge moving as a whole. Even if we admit, however, in the absence of any reason to believe otherwise, that a moving charge is equivalent to an element of current, we cannot look upon the moving ion as equivalent to a complete conducting circuit coinciding with the orbit, as Preston evidently does, for a conducting circuit is the seat of electromagnetic effects throughout its whole length at once, which are constant so long as the current-strength does not change; whereas the electric and magnetic quantities due to a moving charge are functions of the instantaneous position and velocity of the ion, and are not directly affected by the position and velocity at any other point of the orbit.

Voigt[1] has published a theory in which he shows that by introducing into the equations of motion terms of a suitable form he can account for many of the complicated effects that have been observed. The theory is unsatisfactory in that no physical reason is offered why such terms should be brought in. An interesting point is the prediction that in the case of the triplet in a weak field the red component should be more intense than the violet, and not so far from the central line, a prediction that has been verified by Zeeman[2] for a number of lines.

EXPERIMENTAL METHODS.

In every case the source of light in these experiments was an electric spark between terminals (generally metallic) in air. A few attempts were made to work with the oxyhydrogen flame

[1] *Loc. cit.* [2] *Roy. Acad. of Sci., Amsterdam*, Dec. 30, 1899.

and with a vacuum tube, but in neither case could sufficient light be thrown on the grating to make the lines bright enough to see or photograph. The spark was placed between the poles of a strong electro-magnet and the light from it focused on the slit of a concave grating spectroscope, the mounting of which was of the usual type with the slit at the vertex of the right angle, the grating and camera-box being at opposite ends of the movable hypotenuse. The spectra were photographed upon plates 11 inches long and 1¼ inches wide (with a few exceptions), which, after being developed, fixed, and dried, were measured on a dividing-engine designed by Professor Rowland and made under his direction, especially for the construction of his table of the solar spectrum. Separate records were kept in different notebooks of the circumstances under which each plate was taken and of the measurements taken on the dividing-engine.

The plan of the general arrangement of apparatus is as follows: An alternating current of 133 cycles per second, and 100 volts electromotive force was received from the dynamo room and passed through the primaries of three step-up transformers. The secondaries were connected in series, giving a total E. M. F. of 750 volts in the secondary circuit. The secondary current was passed through the primary coil of a large induction coil, the secondary terminals of which were connected to the spark terminals placed between the poles of the magnet. They were also connected with the inner and outer coatings of a battery of Leyden jars, each of about one gallon capacity. In most cases six of these jars were used, but sometimes a less number. In a few instances a small self-induction was introduced in the circuit including the Leyden jars and the spark, in order to make diffuse lines sharper. Without the self-induction the spark was thick and bright and made a loud tearing sound. The presence of self-induction caused a slight flame-like appearance on the side of the spark, similar to that seen in the carbon arc, and deadened the sound to a considerable degree. As a rule the spark was only one or two millimeters long, because if the gap were made wider the current would take the shorter path through

the pole-tip of the magnet. Attempts were made to prevent this by putting layers of insulating material between the pole-tips and the terminals; but in every case the current would pierce them; so that it was found far better to use nothing of the kind.

The terminals were sometimes rods of the metal to be investigated, about ⅛ inch in diameter and 4 inches long; sometimes larger pieces soldered or screwed to brass rods of this size. Often one terminal was of the metal to be investigated and the other of brass, or of another metal having lines in the same region. In the latter case the spectra of two substances appeared on the same plate, which was never a disadvantage, and sometimes was a help. For getting the spectrum of nickel a five-cent piece was found most convenient, as the alloy used in these coins is non-magnetic. Some trouble was experienced in using iron terminals, owing to the force with which they were attracted to the magnet, but they were finally held rigidly in place by fastening them between screws on pieces of board just long enough to reach between the flanges of the magnet. Later some plates were taken of the spectrum of the spark between small carbon terminals, and it was found that the spectrum of iron, as well as those of some other impurities, came out very strongly. Indeed, some such method as this must be used if measurements of the field-strength are made, for the introduction of iron terminals greatly alters the distribution of the lines of force. For taking the spectrum of mercury a small brass rod was bored out and mercury led up through it from a reservoir, the spark passing between the surface of the mercury and another brass terminal set opposite it. In all cases the terminals were filed or ground as flat as possible to avoid sparking to the pole-tips.

Two different magnets have been used. During the spring of 1898, and all the following scholastic year, a small but powerful magnet of the Ruhmkorff form was used, giving a maximum working field of about 28500 C. G. S. units. It had several sets of pole-tips, but for observations across the lines of force we always used a pair with spherical faces of about ¾ inch radius.

For observations along the field pole-tips with flat faces were used, one of which was bored out to allow the light to pass through. This magnet was so placed that the spark came directly in line with grating and slit, and was arranged so that it could be readily turned through ninety degrees. It was excited by a current of 35 amperes or less, according to requirements.

During the past autumn a much larger magnet was constructed, with the intention of obtaining a field which should be more uniform and more convenient for manipulation than that given by the Ruhmkorff magnet. The pole-tips are perfectly flat and are 1½ inches in diameter; throughout the whole space, except very near the edges, the field is quite uniform when the space between is about 3.4 millimeters wide.

Owing to the size of this magnet it was impossible to place it directly in line with slit and grating, so that it was set out from the wall and the light was totally reflected at right angles by a glass prism, which was replaced by a quartz one for ultra-violet radiations.

The strength of the field was measured by an exploring coil connected with a d'Arsonval ballistic galvanometer in a distant room.

When it was desired to analyze the light for polarization it was made to pass through a large Nicol's prism before passing through glass or quartz.

The light was focused on the slit by means of a converging quartz lens. In the first arrangement the lens used was 1½ inches in diameter, 12 inches in focal length, while that used with the large magnet was 2½ inches in diameter, 21 inches focal length.

The concave grating was ruled with 15,000 lines per inch over a space of 5¾ inches, and its radius was 13 feet 3 inches. It gave very good definition, but none of the spectra were at all bright except the first, which was not used on account of the small dispersion. The third spectrum was used up to wave-length 4600, but beyond that the second had to be used, because owing to an alteration which had previously been made on one

of the carriages, the beam could not be pushed beyond this point.

For wave-lengths below 5000 Seed's "Gilt Edge" plates were used, above this point Cramer's "Isochromatic fast" plates. The length of exposure varied from fifteen minutes to an hour and a half. The negatives were developed and fixed in the usual manner.

A full description of the dividing-engine and its accessories is given by W. J. Humphreys in the ASTROPHYSICAL JOURNAL for October 1897, page 169, so that nothing further need be said of them here.

RESULTS.

The object of this investigation was to study, in a general way, the spectra of various elements in the magnetic field, to determine the law of variation with the strength of the field, and to verify as far as possible the results obtained by others in regard to complicated lines.

For determining the law of variation of $\Delta\lambda$, the separation between the extreme lateral components of the magnetic group, and the strength of the field, a number of plates were taken of the same lines with fields varying from 6125 to 26580 C. G. S. units. One such series was taken with the lines 4678.37, 4800.09, 5086.06 of cadmium, and 4680.38, 4722.26, 4810.71 of zinc, on the same plates, one of the spark-terminals being of cadmium and the other of zinc. A similar series was taken with cadmium and magnesium terminals, giving simultaneously the lines 5086.06 of cadmium and 5167.55, 5172.87, and 5183.84 of magnesium. These lines were selected as offering wide separation together with a considerable variety of complexity. They are the lines for which Preston determined the law that homologous lines in the spectra of similar elements show similar magnetic effects. The lines 4678.37, 4680.38, and 5167.55, are sharp triplets, 4800.09, 4722.26, and 5172.87 are sextuplets, and 5086.06, 4810.71, and 5183.84 are diffuse triplets. After measuring the plates a curve was plotted for each line with field strengths as abscissae and separations as ordinates. The sextuplets appear

PLATE XVI

EFFECT OF A FIELD OF 27000 C. G. S. UNITS ON THE CADMIUM LINES $\lambda\lambda$4678, 4800, AND THE ZINC LINES $\lambda\lambda$4680, 4722, 4810

as such only in the strongest fields, therefore in measuring them they were treated as quadruplets, the measurement given as $\Delta\lambda$ being the distance between the mean of the two lateral com-

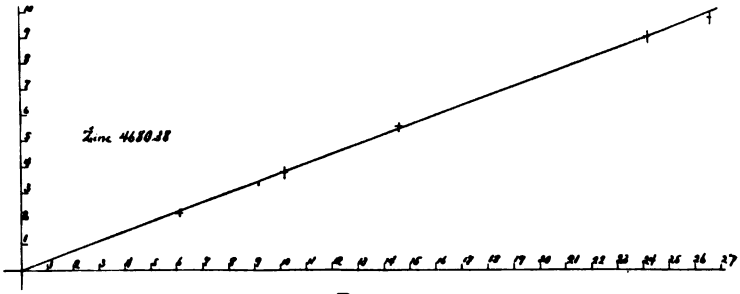


FIG. 1.

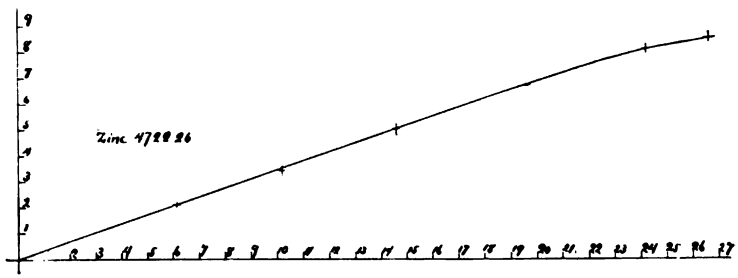


FIG. 2.

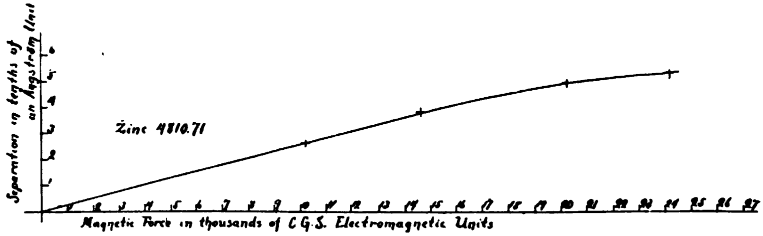


FIG. 3.

ponents on one side and that of those on the other. The appearance of these lines is illustrated in Plate XVII.

The pair of lines at *b* are polarized normal to the lines of force, those at *a* and *c* along the lines of force.

The curves obtained for the three zinc lines are shown in Figs. 1, 2, and 3. The curve for the triplet is perfectly straight

within experimental errors, except that it shows a slight tendency to droop at the highest field attainable, as if the separation approached a limiting value. This tendency is very slight, however, and may merely be due to an error in measurement. The curve for the quadruplet, however, shows this tendency to a greater degree, and in that for the diffuse triplet it is quite pronounced, beginning at a field-strength of 20200 units, the lower portion being still very straight. It must be admitted that in this case the measurements of $\Delta\lambda$ are not so reliable as those given in Figs. 1 and 2, owing to the character of the line, but I do not think errors of measurement can account for such a great deviation from a straight line. The curves for the cadmium lines 4678.37, 4800.09, and 5086.06 are almost identical respectively with Figs. 1, 2, and 3, except that the curve for 5086.06 is not complete, this being a rather hard line to photograph. The three magnesium lines also gave curves of the same character, although here the curve for the sharp triplet 5167.55 shows no tendency to droop, while this tendency in the case of the other two lines is less marked than with the corresponding lines of zinc and cadmium. I do not regard the results with the magnesium lines as being quite so trustworthy as those with zinc and cadmium, as the magnesium lines, especially 5167.55, were hard to photograph, and on most of my plates all three are rather faint, making accurate measurement of the separation difficult. Moreover, measurements on the zinc and cadmium plates are each the mean of eight observations, while only four were taken on the magnesium plates.

In taking these plates a Nicol's prism was used to block out light polarized in a plane normal to the lines of force, except in the stronger fields, where the separation was strong, for all these lines are shaded on one side, especially in the weaker fields, and the "diffuse triplets" were never clearly separated. It seems to be a general law, so far as my observations go, that in the case of heavily shaded lines the effect of the field, apart from the true separation of the Zeeman effect itself, is to destroy the shading and make the line sharper. Besides the above-mentioned

lines, this is shown in the magnesium lines 3838.44, 3832.46, and 3829.5.

Another means of making the lines sharper is self-induction in the spark circuit. This also has the effect of making them fainter, an effect which seems to be more marked for some substances than for others. Some plates were taken in this way, using cadmium and zinc terminals, of the lines 4678, 4722, 4800, and 4810, and it was found that the zinc lines were rendered scarcely visible by an amount of self-induction which left the cadmium lines still of a fair intensity.

My plates in this region confirm Preston's results with reference to corresponding lines in the spectra of cadmium, magnesium, and zinc. As already remarked, three of the lines are sharp triplets, three are sextuplets, and the other three are diffuse triplets, which on my plates show no indications of a more composite character. For each of these lines the value of $\frac{\Delta\lambda}{H\lambda^2}$ was calculated, using the lower straight portion of the curve for this purpose, and the values are given below, λ and $\Delta\lambda$ being measured in centimeters, and H in C. G. S. electromagnetic units.

Substance	Line	$\frac{\Delta\lambda}{H\lambda^2}$
Cadmium	4678.37	17×10^{-5}
Cadmium	4800.09	15.5×10^{-5}
Cadmium	5086.06	10.5×10^{-5}
Zinc	4680.38	17×10^{-5}
Zinc	4722.26	15.3×10^{-5}
Zinc	4810.71	11.3×10^{-5}
Magnesium	5167.55	16.7×10^{-5}
Magnesium	5172.87	14.9×10^{-5}
Magnesium	5183.84	10.5×10^{-5}

Preston gives the relative values 17 for the sharp triplets, 14.8 for the sextuplets, and 9.53 for the diffuse triplets. Probably he determined these values in a strong field, where, as we have seen, $\Delta\lambda$ does not increase so rapidly for the sextuplets and diffuse triplets as for the sharp triplets, and this probably accounts for the relatively lower value of $\frac{\Delta\lambda}{H\lambda^2}$ which he obtained for these lines.

I tried to determine whether the law of correspondence between homologous lines held for other members of the second subordinate series and for those of the first subordinate series, but the character of these lines is so bad that nothing definite can be said of them in regard to this point.

In the case of the cadmium line 4800.09 an attempt was made to measure the space between the lines in the outer pairs of the sextuplets in Plate XVI. The value obtained was 0.136 Ångström units, the value of $\Delta\lambda$ at the same time being 0.877 Å. U. This value is probably too large rather than too small, as the tendency is to overestimate the interval between such close lines. On the same plate the distance between the components of the inner pair was 0.255 Å. U.

A more remarkable line in the spectrum of magnesium is 3832.45. When in a magnetic field it consists of five (or possibly six) components, viz., a very strong central line or pair of lines, and two others on each side of it as shown in Plate XVII. The two faint extremes and the strong central line are polarized in a plane through the lines of force, the other pair in a plane normal to the lines of force. For a field strength of 28500 the separation between the faint extremes is 0.598 Å. U.; that between the pair polarized normal to the field, 0.228 Å. U.

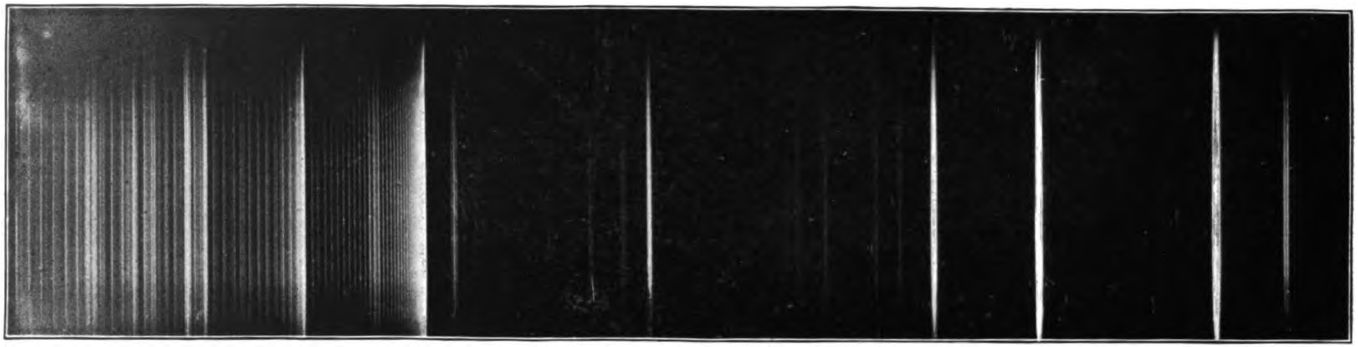
The only other magnesium line for which any satisfactory measurements were obtained is 3838.4. This becomes a triplet of the usual type, rather diffuse. Its separation is 0.336 Å. U. for a field of 28500 units.

The zinc line 3075.99 becomes a very sharp triplet. Its separation is 0.300 Å. U. for a field of 26500.

The cadmium lines 2763.99 and 3403.7 seem not to be affected by the field at all, and 2980.8 shows only a broadening for a field of 28500. For the same field 3252.2 becomes a quadruplet with separation 0.488 Å. U. between its components polarized parallel to the field and 0.179 Å. U. between those polarized normal to the field.

The cadmium lines whose separation is given in the following table are all triplets in the magnetic field.

PLATE XVII



EFFECT OF A FIELD OF 25000 C. G. S. UNITS ON LINES OF CARBON, IRON, CALCIUM, ALUMINIUM, AND MAGNESIUM

CADMIUM.

Line	Strength of field			
	28500	27000	26400	20200
3081.03	0.770	.....	.....	.....
3261.17	0.402	.....	.....	.....
3466.33	.....	.....	.....	0.200
3610.66	0.410	.....	.....	.....
3613.04	.....	.....	0.320	.....
4415	.....	0.459	.....	.....

In the spectrum of nickel the lines 3424.2 and 3510.5 seem to be unaffected, while 3597.8, 3610.6, 3612.8 become quadruplets which are too faint on my plates to be measured under the microscope; but by comparison with neighboring lines it was estimated that the separation of their lateral components (in a field of 28300 units) was in each case rather greater than 0.4 Å. U. For the following lines, all triplets, the separation is given for a field of 28300 units.

NICKEL.

Line	$\Delta\lambda$	Line	$\Delta\lambda$
3370.6	0.353	3493.1	0.301
3381.7	0.318	3515.2	0.324
3414.9	0.374	3524.7	0.391
3446.4	0.350	3566.5	0.338
3458.6	0.292	3619.5	0.363
3461.8	0.377	3858.4	0.441
3472.7	0.467	5371.6	0.594

The spectrum of iron was the first studied in this investigation. A number of plates were first taken from wave-length 3500 to wave-length 4400. Of the lines in this region 3746.06, 3767.34, 3850.12, and 3888.67 seem to be unaffected, and 3722.72 and 3872.64 become quadruplets. Three lines, viz., 3587.13, 3733.47, and 3865.67, exhibit a peculiar state of polarization. Although they are triplets, the inner component is polarized along the lines of force and the outer components at right angles thereto, that is, just the reverse of the usual way.

This phenomenon was first observed for one of these lines by Becquerel and by Deslandres.[1] In comparing the separation of the lines between 3900 and 4450, it was at once observed that the lines could be broken up into two classes, in each of which the separation of the various lines was of the same magnitude. These two classes are identical with those for which Humphreys[2] found that the shift due to pressure was the same. On these plates the separation is very small in all cases owing to a weak field, and no accurate measurements were taken of the separation.

Plates have since been taken of other regions of the iron spectrum with much stronger fields. Four other quadruplets occur, viz., 3466.0, 3475.6, 3490.7, and 3587.13. In the case of the first two a Nicol's prism was used, which showed that in each case the inside pair of the components was polarized normal to the field, the outer pair along the field. The separation of the outer pair in the several cases is respectively 0.76, 0.50, 0.48, and 0.40 Å. U.

Only between wave-lengths 3600 and 4050 are the separations of iron lines determined for measured strength of field. This was accomplished, as noted above, by taking the spectrum of a spark between carbon terminals, the iron appearing as an impurity. The separation of these lines is given below for a field of 25000 units.

IRON.

Line	$\Delta\lambda$	Line	$\Delta\lambda$
3709.39	0.291	3820.59	0.236
3720.05	0.224	3826.03	0.226
3727.78	0.287	3860.06	0.311
3735.01	0.269	3886.43	0.309
3737.28	0.209	3895.80	0.292
3749.63	0.265	3899.85	0.307
3758.38	0.239	3920.41	0.311
3767.34	very small	3923.05	0.310
3815.99	0.239	3928.08	0.305
3930.45	0.311	4063.98	0.247
3968.	0.334	4071.90	0.154
4045.98	0.282		

[1] *Comptes Rendus*, April 4, 1898, p. 997.

[2] This JOURNAL, 6, 200, October 1897.

Some lines in the spectra of calcium, aluminium, and silicon also appeared as impurities in the carbon spectrum.

The aluminium line 3961 in a magnetic field is a triplet with separation 0.242 Å. U., while 3944 is a quadruplet with separation 0.279 between its components polarized parallel to the field and 0.138 between those polarized normal to the field.

The calcium line 3933 becomes a triplet whose separation is 0.222, 3968 a quadruplet whose components polarized parallel to the field are separated 0.282 Å. U., those normal to the field 0.144 Å. U.

The silicon line 3905 shows a separation of 0.209 Å. U. It is a triplet.

All the measurements given for the lines of aluminium, calcium, and silicion, were taken from the same plate, the field strength being 25000 units. On this same plate the carbon band between 3800 and 3890 shows no indication of magnetic effect.

The only titanium lines observed are 3658.3, 3759.4, 3761.4. All these become clean, sharp triplets. The separations for a field of 25000 units are respectively 0.272, 0.314, 0.247.

A few lines have been studied in the spectrum of mercury. In the following table the separation is given for a field of 24500 units.

MERCURY.

Line	$\Delta\lambda$	Line	$\Delta\lambda$
5460.97	0.756	4046.78	0.669
4078.05	0.493	3984.	0.350

All of these lines are diffuse, especially 5460.97, which may be of more complicated form than a triplet, as Blythswood and Marchant[1] found with the echelon spectroscope. The above value of $\Delta\lambda$ for this line agrees with that given by them as well as could be expected from the character of the line.

On one of my plates, taken of the spectrum of a spark between magnesium and cadmium, a group of air lines appears at

[1] *Phil. Mag.*, April 1900, p. 384.

about 4650. Although not clearly separated, owing to their diffuse character, some of them show unmistakable evidence of magnetic effect, and a few rough measurements were made to get an idea of the effect on air lines. For one the separation was estimated at 0.9 Å. U., for another at 0.4 Å. U., and for a third at 0.3 Å. U., while the rest could not be measured. These figures are not to be relied upon, as all the lines are quite diffuse.

A paper has recently been published by Zeeman,[1] in which he partially confirms Voigt's prediction by theory that for a triplet in a weak field the red component would be found stronger than the violet, but not separated so far from the central line. Although none of my plates were taken with a view to testing this theory, a search was constantly made for lines not symmetrical in separation. Many lines occurred where first measurements indicated asymmetry, but in most cases the definition was not good enough to warrant putting faith in the measurements, or else a more careful remeasurement showed that the first result was wrong. In the following instances, however, there really seems to be a difference in the separation on the two sides:

1. In the iron quadruplet 3466.0, the mean of the inner pair of components is a trifle farther toward the red than that of the outer pair.

2. In the triplets 4678.37 of cadmium and 4680.38 of zinc, the violet component is farther from the central line than the red component in a field of 24100 units, but both appear equally distant in a field of 26580 units.

3. In the sextuplets 4800.09 of cadmium and 4722.26 of zinc, the mean of the inner pair is a little farther toward the violet than the mean of the outer doubles in a field of 24100 units, but the group becomes symmetrical in a field of 26580 units.

As regards intensity, the above lines of cadmium and zinc as well as the lines 5086.06 of cadmium, 4810.71 of zinc and 5167.55, 5172.87, 5183.84 of magnesium all seem to have the red component stronger than the violet in weak fields. Also in weak fields the iron lines 3743.51, 3581.35, 3570.27, 3526.18,

[1] *Proc. Roy. Amsterdam Acad. Sci.*, Dec. 30, 1899.

and 3878.15 all seem to have the red component stronger than the violet. I have not observed any cases where the violet component is the stronger.

This investigation was begun in February 1898, in collaboration with Mr. Robert Earhart, under the supervision of Professor Ames, and was so continued until June of that year. During the following scholastic year, the writer continued the work, partly alone, partly with the assistance of other students, especially of Mr. J. F. Meyer and Mr. H. J. Lucke. During the present scholastic year he was assisted by Mr. Norton A. Kent, who will continue the work.

In conclusion I wish to express my obligations to Professors Rowland and Ames, and to Mr. Lewis E. Jewell, for their most valuable advice and encouragement.

JOHNS HOPKINS UNIVERSITY,
June 1900.

A NEW THEORY OF THE MILKY WAY.

By C. Easton.

§ 1. My investigations on the apparent distribution of the stars in a part of the Milky Way, undertaken several years ago and published in the Astrophysical Journal, Vol. I, No. 3, March 1895,[1] seemed to indicate that it has a roughly annular structure. However, at the end of these articles I pointed out that there is nothing to prove that all parts of such a hypothetical ring — evidently very irregular in its details — are at the same distance from our Sun, nor even that it is a closed ring, independent of the central part of the galactic system. Moreover, Professor Seeliger, in an exhaustive discussion on the distribution of stars in space,[2] remarks that the conclusions reached in these articles do not necessarily apply to the entire Milky Way; he also thinks that the stellar accumulations of the Milky Way in different directions are probably at different distances.

I now propose to show that the annular theory of the Milky Way is in reality incompatible with the present state of our knowledge of the galactic phenomenon, and as there is little reason to hope that the great problem of the constitution of the visible universe will be definitively solved in the near future, I have added certain general considerations which seem to lead to a new theory of the structure of the Milky Way in space.

§ 2. If we assume that the actual form of the Milky Way corresponds with its apparent form: that of a ring surrounding us on all sides — what position must then be assigned to the Sun?

It does not seem to be situated near the center of the ring. In fact, a single glance at the Milky Way on a clear evening

[1] *Cf. A. N.*, 137, No. 3270.

[2] "Betrachtungen über die räumliche Vertheilung der Fixsterne." *Abh. d. k. bayer. Akademie d. Wiss.*, II Cl., XIX. Bd., III. Abth., 1898.

in August or September reveals a peculiarity which has apparently been given less importance than it merits: the great superiority in brightness of the Milky Way near *Aquila* as compared with that near *Monoceros*. It may be inferred from this that in general the stars are more numerous near the XVIIIth hour than near the VIth hour of right ascension.[1]

This unequal distribution of the stars of the Milky Way, not only in detail, but also for the two halves of the zone as compared with each other, when it is represented as divided along a line through *Crux* and *Cassiopeia*, is still more striking in the results of stellar gauges and enumerations. The mean result of William Herschel's gauges in the region of *Aquila* is 161.5 stars; in that of *Monoceros*, 82.5 stars. Similarly, Celoria, systematically counting the stars to about the eleventh magnitude in an equatorial band six degrees wide, has found 58,883 stars in the half of this band which is traversed by the Milky Way near $XVIII^h$, and only 43,822 in the opposite half.[2]

William Herschel's gauges and Celoria's enumerations include regions of very different areas and embrace very diverse stellar magnitudes; for this reason alone it is almost inadmissible that the divergence indicated can be the effect of a chance accumulation of stellar condensations near the constellation *Aquila*. Furthermore, the aspect of the sky, and the charts of the Milky Way where account has been taken of the general distribution of the galactic light in the various parts of the zone, seem to indicate a certain measure of gradation in the brightness. Encke, in his criticism of Struve's theory,[3] insists that if such a supposition is made—eccentric position of the Sun—values should be given for the stellar density intermediate between the maximum and minimum density; these values must then agree with a quantity determined by the eccentricity.

[1] *Cf.* PLASSMANN, *Mittheilungen der V. A. P.*, III, 1893, Berlin, Dümmler, 1893, p. 102; Easton, *Verslagen d. Kon. Akademie, Amsterdam*, 1897–8, p. 383.

[2] F. G. W. STRUVE, *Études d'astronomie stellaire*, 1847, note 75; G. Celoria, "Sopra alcuni scandagli del cielo," *Pubbl. del R. Osserv. di Brera*, 13, 18.

[3] *A. N.*, 26, 622.

The observations at our disposal at the present time are certainly not sufficiently numerous to permit such an investigation to be undertaken, and it is to be feared that the marked irregularities of a purely local character, in the structure and brightness of the Milky Way, will always stand in its way; but we may at least endeavor to indicate the principal features of the distribution of brightness in the Milky Way.

In his *Uranométrie générale*, Houzeau has enumerated thirty-three bright spots and regions of the Milky Way; he has also estimated their brightness. Although his method (indicated on page 15 of this work) cannot give results of great precision, we may certainly regard as "fairly bright" the spots which he estimates as of magnitude 5–6, and as "bright" those which he estimates as 5 or 4–5. By dividing the entire Milky Way into halves by a line passing through *Crux* and *Cassiopeia*, I find in the half which contains *Monoceros* four or five fairly bright spots and not a single bright spot; in the half which contains *Aquila* I find seven or eight fairly bright spots and seven bright spots. The conclusion is the same as for the gauges of Herschel and Celoria.

Considering only the zone comprised between $-45°$ and $+45°$ I find two fairly bright spots and no bright spot near VI^h, as against six fairly bright spots and five bright spots near $XVIII^h$.

It follows that these apparent accumulations are comparatively most numerous in the region of *Aquila*, between $-45°$ and $+45°$, and that they are least numerous in the opposite zone, near *Monoceros*. From this point of view these two zones, each embracing a quarter of the circumference, are in the ratio of 5.5 to 1, while for the corresponding *halves* of the Milky Way, the ratio is 2.8 to 1. On my chart of the Milky Way it may be seen that the general brightness of the Milky Way diminishes pretty gradually from *Cygnus* to *Cassiopeia;* the same thing occurs between *Ara* and *Navis* in the southern hemisphere. But the gradation is very incomplete: between *α Persei* and *α Aurigae*, for example, the brightness of the Milky Way is much less marked than between *α* and *θ Aurigae*.

Gould remarks (*Uranometria Argentina*, p. 370) in speaking of the Milky Way in the southern hemisphere: "Its brightest portion is unquestionably in *Sagittarius*, that in *Carina* being slightly inferior to this as regards intrinsic brilliancy, although far more magnificent and impressive on account of the great number of bright stars with which it is spangled."

After having indicated this characteristic feature in the general distribution of brightness in the Milky Way, we may attack the problem from a different side.

§ 3. It is easy to imagine the aspect of the heavens, for each of the typical positions which may be assigned to the Sun, from the interior of the Milky Way considered as a stellar ring.

We may then distinguish the five following cases:

a. The Sun occupies the center of the ring. In this case the Milky Way will appear as a more or less irregular luminous band, in which the irregularities in the distribution of the stars (dark and bright spots, richness in bright stars, unequal width of the zone) are not grouped systematically with reference to any given point of the circumference.

b. The Sun occupies an eccentric position.—The brightness of the Milky Way is less marked near 180° than near 0°, rapidly increases up to a point beyond 90° (270°), then more gradually or insensibly to about 0°. Between 180° and 90° there are many bright stars; these become less numerous as the zero point is approached. The width of the Milky Way is greater near 180° than near 90° (Fig. 1).

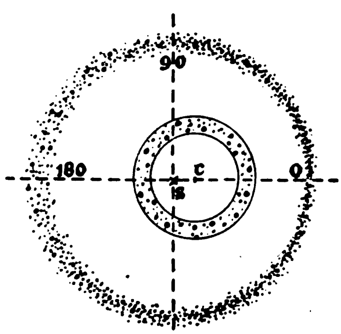


FIG. 1.

c. The Sun is situated on the inner edge of the ring.—The difference in the width of the Milky Way near 0° and near 180° is much more marked; the maximum of faint stars occurs between 0° and 90°, that of the bright stars at about 90°. Near 180° the Milky Way is very broad, vague, and very faint; whether the galactic light

in this part of the sky is still even perceptible will depend on the thickness of the ring (Fig. 2).

d. The Sun is situated in the body of the ring.—Towards 180° no trace of the Milky Way will be visible, nor will the bright stars be very numerous in that region. Between 180° and 90° a faint galactic glow commences to appear, which increases pretty rapidly toward 90°; the bright stars also become more numerous and are seen in greater number beyond 90°. At first scattered, between 180° and 90°, over nearly a semi-circumference, the galactic glow grows narrower and narrower, becoming at the same time more brilliant, and the brightness attains its maximum between 90° and 0°. The Milky Way is narrowest near 0° (Fig. 3).

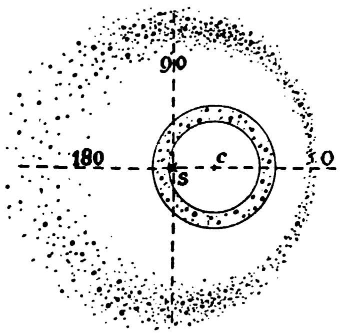


FIG. 2.

e. The Sun is situated on the outer edge of the ring.—The phenomenon which I have just described under *d* can hardly be called "Milky Way," but in this last case (*e*) nothing is seen but a spindle-shaped nebulous glow occupying less than half a great circle, with a long and narrow condensation. An immense mass of stars, of a somewhat nebulous appearance, and an empty sky surrounding them.

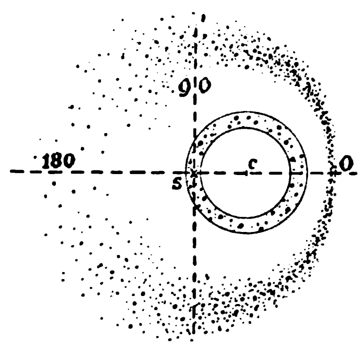


FIG. 3.

§ 4. The general aspect of the Milky Way, as it appears to us, and the result of stellar gauges and enumerations to which reference has already been made, would correspond very well with case *b* if it were not for an important exception regarding the *width* of the zone.

The limits of the Milky Way are so vague that it is impossible to measure the width exactly on the drawings. According

to the charts by Boeddicker and myself, the Milky Way is a little wider near *Monoceros* than near *Aquila*, taking into account the separate branches; according to Gould's chart, on the contrary, it is a little wider near XVIII^h.[1] However this may be, in the theory of a galactic ring one would expect to find a very striking difference *in width*, as the difference between the *brightness* of the opposite regions is so evident.

But we possess a surer means of measuring the width of the Milky Way, independently of the optical phenomenon, *i. e.*, the width of the zone where the stellar density is higher than the average. In discussing the results of his stellar enumerations, Celoria (*loc. cit.*, tav. V.) gives diagrams of the stellar density in an equatorial zone 6° wide, (1) for the stars of Argelander's *Durchmusterung*, (2) for the stars to about the eleventh magnitude, counted at Milan, (3) for the stars comprised in W. Herschel's gauges between +20° and —20°, corresponding to Celoria's zone. By measuring the horizontal projection of the curves which rise above the mean, the following results are obtained:

a. When only the stars of the *DM*. are considered (magnitude about 0–9.5), the Milky Way is about 5° wider near VI^h than near XVIII^h.

b. For Celoria's stars, on the contrary (magnitude about 0–11), the Milky Way is about 18° wider near XVIII^h than near VI^h.

c. The gauges of W. Herschel (magnitude 0–14?) similarly indicate that the Milky Way is about 4° or 5° wider near XVIII^h than near VI^h.

Thus, *for the faint stars taken as a whole, the Milky Way is widest in its brightest part*, and at least for Herschel's gauges, this certainly cannot be explained by local causes.

This result is evidently not in harmony with case *b*, § 3, which is nevertheless the only supposition that seems to correspond with the appearance of the sky and the result of the star gauges,

[1] Boeddicker, *The Milky Way*, London, Longmans, and New York, Scribner, 1892; Easton, *La Voie lactée*, Paris, Gauthier-Villars, 1893; Gould, *Uranometria Argentina*, 1879.

in the theory of an annular Milky Way. This theory thus leads us to the following dilemma: the galactic ring is a ring the chance irregularities of which are markedly, one might even say systematically, grouped with reference to a certain part of the circumference—which is extremely improbable—or else it broadens considerably in one half of the circumference, which appears no more probable.[1]

§ 5. May it not be that the anomaly which we have just noted in the width of the Milky Way near XVIII^h, as compared with the opposite part of the zone, is due to the fact that the ring is really double, over nearly one half of its circumference, as it is shown in the old drawings of the Milky Way?

At first sight it would seem strange that, for one of the halves of the ring, there should exist, not a division, but an actual duplication—for twice as many stars are counted on the "two branch" (*Aquila*) side as on the opposite side—and especially since the classic division of the galactic zone into two *distinct and separate* branches, between *Cygnus* and *Centaurus*, no more exists than the single band between *Cassiopeia*, *Monoceros*, and *Crux;* this follows from all the evidence of the modern charts and photographs of the Milky Way. On the one hand the northern (secondary) branch of the Milky Way is not a single and continuous stream, and the part between δ *Cygni* and γ *Ophiuchi* cannot be regarded as the continuation of the luminous regions toward *Scorpius* and δ *Ophiuchi;* and on the other hand the ramifications properly so-called seem to be even more numerous in the part which was formerly regarded as single than in the "double" part of the Milky Way.

With a little good will it is possible, however, to trace a zone, starting from ϵ *Cassiopeiae*, through γ and δ *Cygni*, ϵ *Aquilae*,

[1] Sir John Herschel (*Outlines of Astronomy*, § 788) assigned to the Sun an eccentric position in the Milky Way on the side nearest the southern parts of the zone, on account of their great brightness and their better defined boundaries. Proctor has followed the same reasoning for the construction of his spiral (*Monthly Notices*, 30, 50). From what precedes one would infer, on the contrary, that the Sun is, in general, nearer the vague and faintly luminous parts of the Milky Way. Proctor's "spiral," moreover, explains none of the principal features of the galactic phenomenon, although it led its author to make interesting remarks.

θ Ophiuchi, and terminating at *α Centauri*, in which the galactic light is in general more brilliant than between this zone and the principal branch of the Milky Way. It is even possible to regard the faintly luminous streams between *ζ Persei*, *δ Orionis*, and *ε Canis Majoris* as the continuation of this "secondary" Milky Way, and also to connect it with "the belt of bright stars" of John Herschel and Gould, extending through *Taurus*, *Orion*, *Crux*, *Scorpius*, etc. We should thus have an indication of two principal planes, in which are grouped both the bright and the faint stars of the Milky Way.

It may be remarked that Celoria (*loc. cit.*, 42; *cf.* Gould, *loc. cit.*, 381) by a process of reasoning different from that which has led us to reject the theory of a single ring, reaches the conclusion that there exist *two galactic rings*, inclined to each other at an angle of 19° or 20°, one of which contains principally the fainter stars, the other the bright stars. Celoria is unable to decide whether these two rings coincide at the point where they appear to touch. The principal ring, composed particularly of faint stars (*i. e.*, distant stars, in Celoria's hypothesis) would be projected on the sphere in a great circle traversing *Sagitta*, *Auriga*, *Monoceros*, *Scutum;* the secondary ring would include the branch of the Milky Way in *Ophiuchus*, the branches in *Orion*, the *Hyades*, the *Pleiades*, and the belt of bright stars.

§ 6. Assuming that the belt of bright stars and the secondary branch of the Milky Way (which seems to be the cause of the incompatibility between the aspect of the Milky Way and the annular theory) are due to the same cause: the existence of a *secondary galactic ring*, it will be noticed that the belt and the secondary branch are, so to speak, complementary; the bright stars are numerous where the secondary Milky Way is very faint—*Taurus*, *Orion*, etc.—and, on the contrary, the belt of bright stars is almost wholly effaced where the secondary branch of the Milky Way is fairly bright—*Ophiuchus*, *Cygnus*. Thus, for this secondary galactic ring, the position of the Sun should correspond with case *c*, § 3—and hence the secondary ring must be *much smaller* than the principal ring—while this position will

be intermediate between cases *b* and *a* so far as the principal ring is concerned.

If now we place the center of the secondary ring at some distance from the center of the principal ring, and outside of the principal plane, the Sun being near the line of intersection of the two planes $p\ I\ p'$ (Fig. 4*a*), the *general features* of the galactic

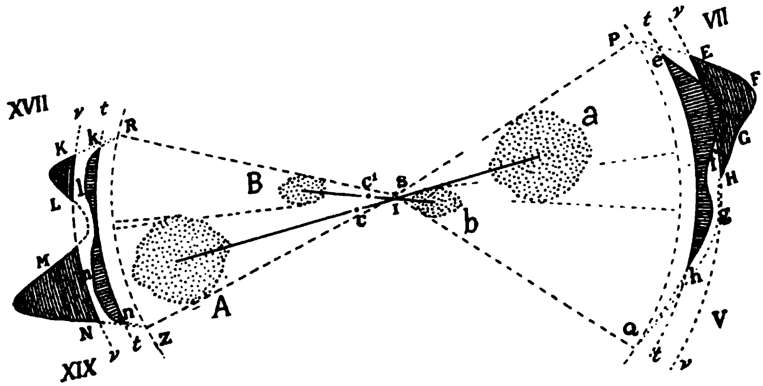


FIG. 4.

phenomenon are fairly well explained by what we may call Celoria's modified theory.

In Fig. 4 let *c* and c^1 be the centers of the two galactic rings, whose equatorial sections are *A*, *a* and *B*, *b*; let *I* be the projection of the line of intersection of the two galactic planes, and *S* the position of the Sun; the angle *PSQ* will be greater than the angle *RSZ*. For the stars of the *DM.*, *a* and *b* unite to produce a density greater than the average near VI^h, because stars of various magnitudes are mingled together in the Milky Way, and because, consequently, there is also a surplus of bright stars near *a*, although the great majority of the stars at *a* (*i. e.*, of the outer galactic ring) escape observation, which nevertheless includes the greater part of the stars of *b*, the interior ring. All that is above the average density (theoretical Milky Way)[1] for the stars of the *DM.* is indicated by the curve *efgh*. But Herschel's

[1] The *optical* Milky Way, which is a rather complex and purely subjective phenomenon (*cf.* my *Milky Way*, Introduction, p. 12), thus resembles a theoretical Milky Way composed of a great number of telescopic stars fainter than magnitude 9.5.

gauges contain the greater part of the faint stars included in *a*, while in the direction of *b* the number of stars increases in a much less rapid proportion; in fact, hardly increases at all beyond a certain telescopic power. The Milky Way for Herschel's stars will be indicated by the curve *EFGH*, less extended than the curve *efgh*. Near XVIII^h, on the contrary, especially on account of the distance of *B* as compared with *b*, the stars of the interior ring contribute in an important degree toward the formation of the Milky Way, and this narrowing of the Milky Way in proportion as the number of telescopic stars increases will be less sensible; for the telescopic stars the Milky Way may be as broad as, or even broader than the zone near VI^h. The density of the Milky Way in the direction of XVIII^h will be greater on account of the greater distance; therefore it will also be more brilliant.

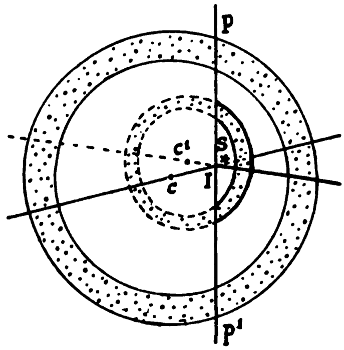


Fig. 4*a*.

The Sun cannot be very far from the line of intersection of these two principal planes of the Milky Way, which terminate in *Cassiopeia* and *Crux*, a distance of about 180°. This forces us to place the center of the secondary (interior) ring rather distant from the plane of the principal ring, which appears to be a weakness in this theory. If we could assume the existence of an actual condensation of stars in the direction of *B* (see Fig. 4), this would explain the brilliancy of the Milky Way in the direction of *Cygnus* and *Ophiuchus*, and we would be free to make the interior ring still smaller and to bring the center c^1 nearer the point *I*. We shall see in what follows that there in fact seems to be a plausible reason for making such an assumption.

§ 7. However, all that has been learned regarding the constitution of the Milky Way since the ingenious investigations of the Italian astronomer — more thorough studies of the Milky Way with the naked eye, structure of galactic clouds revealed

by photography, etc. — forces us to admit that the Milky Way cannot be composed of two distinct, uninterrupted rings, as Celoria believed ("due anelli distinti, nè mai interrotti nel loro corso," *loc. cit.*, p. 41). In reality, the structure of the Milky Way, even in its principal features, must be much more complicated.

Nevertheless this fact does not require us to reject all the considerations set forth in the above paragraphs. On the contrary, although the irregularity of the Milky Way is evident enough so far as the details of the zone are concerned, and although the situation of our Sun makes it very difficult for us to discover a definitive arrangement of the stars and stellar groups which surround us on all sides in the plane of the Milky Way — there are nevertheless indications that regularity is not altogether lacking in the distribution of the galactic stars; evidence that, so to speak, our stellar system possesses a certain degree of organization.

Let us first pass in review these indications, and subsequently consider the modifications which can advantageously be made in the theory stated in § 6.

I need not here dwell upon the fact — first pointed out by William Herschel (although contradictory to his first hypothesis of the uniform distribution of all stars in space): the reality of the clustering tendency which is seen in certain parts of the heavens. While in certain regions of space the distances between stars are enormous and the stars are quite alone or grouped only in binary and triple systems, etc., there are other regions where the original matter has condensed in star clusters, and still others where accumulations of stars of different magnitudes occupy very extensive regions of celestial space. Bauschinger and Sidney Waters have pointed out the correlation between these last two phenomena, *i. e.*, that star clusters for the most part follow the ramifications of the Milky Way. The same is true, it would appear, of diffused nebulosities.

It nevertheless does not follow that there must exist an organic connection between the stellar groups of the Milky Way,

nor that the stars which are clustered together, and those which are relatively isolated, should form two independent systems.

§ 9. If it is no longer possible to regard the stellar accumulations of the Milky Way, taken as a whole, as a ring, or even as two interlacing rings, the aspect of the Milky Way by no means excludes the existence of annular segments or of streams or strata of stars.

The majority of the stars seem to be grouped in two principal planes. This conclusion, developed in Celoria's investigations, is found in slightly different form in the writings of John Herschel and Gould ("belt of bright stars," "cluster of bright stars." *Cape Observations*, 1847, § 321; *Uran. Argent.*, 368). Ristenpart states that the principal plane of the Milky Way is not a broken plane, but is composed of two planes slightly inclined to each other.[1] Struve, who preferred a "broken plane," did not exclude the idea that "the most condensed layer of stars lies in two planes" (*Et. d'astr. stell.*, 1847, p. 82).

Such an arrangement of the greater part of the stars in two planes, slightly inclined to each other, would appear hardly compatible with the idea of a purely fortuitous distribution of the stars in the galactic layer.

§ 10. The aspect of the Milky Way does not correspond to the projection of agglomerations distributed by chance in space, which would rather produce series of superposed spots, for the most part condensed toward the center, and in general more numerous and more brilliant as the galactic equator is approached, without characteristic differences in the various portions of the zone.

On the contrary, in many parts of its course the Milky Way is composed principally of stellar beds or streams, frequently irregular, it is true, but of a character which differs essentially from the appearance which would be produced by the projection of irregular clusters situated at different distances (*cf.* the photographs of the regions surrounding *Crux*, *Scorpius*, *ε Cygni*, *δ Cephei*, etc.)

[1] *Veröffentl. grhz. Sternw. Karlsruhe*, 1892, p. 67.

Furthermore, it follows from even a superficial study of the aspect of the Milky Way that the constitution of the belt exhibits characteristic differences when extensive and widely separated parts are compared among themselves. Relatively uniform regions immediately follow flocculent regions; here series of spots are seen, there ramifications extending over enormous distances. As examples we may cite the Milky Way in *Sagittarius* and *Scutum*, in *Cygnus* and *Lacerta*, in *Cassiopeia* and *Perseus*.

It is also a remarkable fact that the gradation of the light in passing from the edges toward the middle of the belt is very different in different parts of the Milky Way. Thus, in the principal branch which passes through α *Aquilae*, the brightness decreases gradually from the inner edge toward the outer boundary, while in the secondary branch (from *Lupus* to *Camelopardus*) the luminosity is much more uniform. The region between γ *Sagittae* and ν, δ, and β *Cygni* is an exception: the principal branch here appears vague and dull, and a great bright spot extends from γ to β *Cygni*, encroaching a little on the dark interval.[1]

§ 11. In addition to these characteristic features there is the tendency to form streams and branches. Sir John Herschel, who was perfectly acquainted with the telescopic structure of the Milky Way, called attention to the fact that in the southern hemisphere he saw a series of star clusters distributed along a luminous band of the Milky Way, while no cluster was visible in the dark interval between the galactic branches.[2] He speaks elsewhere of fainter and less clearly defined streams and again of the tendency of the secondary streams to unite with the principal stream.[3]

Telescopic observation suggested to him still more precise ideas. "In some [regions], for instance," he remarks, "extremely minute stars, though never altogether wanting, occur in numbers so moderate as to lead us irresistibly to the conclusion that in

[1] Gould, *loc. cit.*, 381; Easton, *Voie lactée*, Description, pp. 41, 47.

[2] J. Herschel, *Cape Observations*, 1847, p. 387; *cf.* Sidney Waters, *Monthly Notices R. A. S.*, LIV.

[3] *Ibid.*, p. 386.

these regions we see *fairly through* the starry stratum, since it is impossible otherwise (supposing their light not intercepted) that the numbers of the smaller magnitudes should not go on continually increasing *ad infinitum*. . . . In other regions we are presented with the phenomenon of an almost uniform degree of brightness of the individual stars, accompanied with a very even distribution of them over the ground of the heavens, both the larger and the smaller magnitudes being strikingly deficient. In such cases it is equally impossible not to perceive that we are looking *through* a sheet of stars nearly of a size, and of no great thickness compared with the distance which separates them from us. Were it otherwise we should be driven to suppose the more distant stars uniformly the larger, so as to compensate by their greater intrinsic brightness for their greater distance, a supposition contrary to all probability. In others again, and that not infrequently, we are presented with a double phenomenon of the same kind, viz., a tissue as it were of large stars spread over another of very small ones, the intermediate magnitudes being wanting. The conclusion here seems equally evident that in such cases we look through two sidereal sheets separated by a starless interval."[1]

In several parts of the Milky Way one notices (not on the photographs, which are incomparable for the study of the structure of the details, but do not bring out the greater features of the galactic image) what Dr. Boeddicker calls "the tendency to duplication;" this tendency is particularly noticeable in *Cassiopeia* and *Perseus*.[2] It would seem very difficult to reconcile this phenomenon with the absence of all structure in the Milky Way.[3]

[1] *Outlines*, § 797.

[2] BOEDDICKER, *Monthly Notices R. A. S.*, L, No. 1; Easton, *Voie lactée*, Plate III and Description, p. 49.

[3] I cannot here enter into a discussion of the much disputed question of the reality of "star drifts" (Proctor), ellipses and wreaths (Holden), lines of stars (Ranyard, Backhouse), etc.

It is equally impossible in this necessarily limited discussion to consider the interesting investigations which treat of the relation of the galactic plane to the distribution of the various spectral types, Wolf-Rayet stars, new stars, etc., by Dunér, Pickering, McClean, Campbell, Kapteyn, and others, nor the investigations on the distribution of nebulæ, the constitution of the Magellanic clouds, etc.

§ 12. The dark spots and bands in the Milky Way particularly merit our attention. A well-known argument of Sir John Herschel is drawn from the fairly regular dark spots; "When we see, as in the coal-sack, a sharply-defined oval space free from stars, insulated in the midst of a uniform band of not much more than twice its breadth, it would seem much less probable that a conical or tubular hollow traverses the whole of a starry stratum, continuously extended from the eye outwards, than that a *distant* mass of comparatively moderate thickness should be simply perforated from side to side, or that an oval vacuity should be seen foreshortened in a *distant* foreshortened area, not really exceeding two or three times its own breadth."[1]

The "coal-sack" near the Southern Cross is better known, but is perhaps not more remarkable than certain other similar openings in the Milky Way. I cite in the first place the elliptical spot situated half way between *a Cygni* and *a Cephei*.[2] Notice also the curious little black spots, which so well produce the effect described by Herschel as an "oval vacuity," between *a* and *f Cygni*, on Max Wolf's photographs.[3] As opposed to Sir John Herschel's argument the objection has been raised that the proximity of the dark and bright spots in the Milky Way does not exclude the possibility that in this direction the cosmical matter may be greatly extended in the line of sight, since the probability of the existence of apertures in an accumulation of a limited number of stars does not depend upon the dimensions in the line of sight.[4] A popular objection would be that portions of the sky can always be seen through the foliage of a tree. I think there is a slight error in this interpretation of Sir John Herschel's idea. Two or three leaves form as much of a screen as a thousand leaves, while a thousand stars form a luminous accumulation as compared with a region where the

[1] *Outlines*, § 792.

[2] No. XVII of my catalogue; see also Heis, *Atlas coel. novus*, 1872, and *cf.* Oehl, in *Gruithuisen's Naturw. Astron. Jahrbuch*, IX, 1846.

[3] Reproduced in *Knowledge*, October and December 1891, in Schweiger-Lerchenfeld's *Atlas der Himmelskunde*, and elsewhere.

[4] SEELIGER, *loc. cit.*, 628.

stars are few, and it is precisely this relatively homogeneous character of regions surrounding the "coal-sacks" which suggests the idea of a perforated band. It is true that the limits of these dark spots are not so well defined as Herschel supposed them. (See the "coal-sack" on Russell's photographs and on those of Pickering in the publications of the Henry Draper Memorial); nevertheless, in my opinion, the degree of definition of the edges of these spots and the uniformity in brightness of the surrounding regions are sufficient to sustain Herschel's argument. It is a question of judgment. To take a definite case, it seems to me that the appearance of the regions surrounding the small black spots in the neighborhood of f^2 *Cygni* and θ *Ophiuchi* on the photographs of Wolf and Barnard can only be explained as due to actual holes in a comparatively thin layer of stars.

A similar argument is furnished by the dark bands and fissures in certain parts of the Milky Way. Maunder[1] has already pointed out that these dark lanes are most easily explained as actual openings in the star clouds of the Milky Way. But it is particularly in that part of the Milky Way lying on the boundaries of *Ophiuchus* and *Scorpius* that a magnificent photograph taken by Professor Barnard on June 21, 1895 reveals, between ω *Ophiuchi* and *Antares*, streams separated by dark intervals, which strongly suggest the existence of actual stellar strata, the thickness of which is small as compared with their distance from us (see Plate XI).[2]

§ 13. If the considerations developed in the preceding paragraphs render probable the existence of extensive but comparatively thin strata or streams of stars — which may be projected upon each other in certain parts of the Milky Way — there are also reasons to believe that the various portions of the Milky Way are not all at the same distance from us; reasons additional to those based upon the conclusions which may be drawn from Celoria's investigations (§§ 5 and 6).

[1] *Knowledge*, Feb. 1895, p. 37.

[2] See E. E. BARNARD, this JOURNAL, March 1899, on the very dark openings in the dark bands.

A minute study of the Milky Way in the southern hemisphere led Sir John Herschel to the conclusion that this part of the zone is composed of various portions situated at different distances (*Cape Observations*, § 321). In certain regions he believed that his telescope led his view across two stellar strata, separated by an interval void of stars. Elsewhere he describes the space revealed to him by his telescope as a cone filled with stars for a limitless distance in the line of sight. In this case, however, his reasoning would not appear to be well founded, as has already been indicated by Proctor.[1] But the argument based on the lateral branches of the Milky Way—in the northern hemisphere they are mentioned by Heis (*Draco*), Gould (*Orion*), Easton (*Auriga, Lynx*), and particularly by Boeddicker—would appear to have more weight: "Neither can we without obvious improbability refuse to admit that the long lateral offsets which at so many places quit the main stream and run out to great distances, are either planes seen edgeways, or the convexities of curved surfaces viewed tangentially, rather than cylindrical or columnar excrescences bristling up obliquely from the general level."[2]

It is evident that these lateral branches, which frequently extend to a considerable distance from the galactic equator, are in general much more easily explained by supposing that they extend on this side, and not beyond the principal branch of the Milky Way. Thus some portions of the Milky Way would be comparatively near us.

Another consideration, which is perhaps even more important, is the following. In certain parts of the Milky Way the galactic image, with its bright and dark spots, would appear to be outlined by the distribution of the stars of Argelander's last class.[3] On the other hand, Professor Seeliger has shown[4], by a comparison of the number of stars in the two *Durchmusterungen* with those of William and John Herschel's gauges, that this is not

[1] *Intellectual Observer*, August 1867. [2] *Outlines*, § 792.

[3] EASTON, *Verslagen Kon. Akademie Amsterdam*, 1894–5, p. 187.

[4] *Loc. cit.* 626.

the case for the whole galactic zone. However, there are some regions where even the naked-eye stars are evidently correlated with the distribution of the galactic light, as follows from a simple comparison of the Bonn charts with the most detailed photographs and charts of the Milky Way. I cite especially the luminous spot between α and *A Cygni*, and the northern part of the great spot $\gamma-\beta$ *Cygni*.[1] Unless we suppose gigantic stellar accumulations to exist at this point we are forced to admit that this part of the Milky Way is much nearer to us than the average.

Although it appears from the beautiful investigations of Professor J. C. Kapteyn[2] that the mean distance of stars of a given magnitude is much greater in the Milky Way than outside of this zone, the branches which start from the central part of the Milky Way and include the *Pleiades* and several bright stars in *Orion* seem also to support the conclusion that in certain parts of the Milky Way the small stars are at distances comparable with that of the bright stars.

§14. The galactic region in *Cygnus*, referred to in the preceding paragraph, is very remarkable and in fact quite exceptional as regards its brightness and its situation in the zone.

If we omit questions of detail, that which strikes us most forcibly in studying the aspect of the Milky Way in the northern hemisphere is the fact that the principal branch is exceedingly faint in *Perseus*, and that the secondary branch, very faint elsewhere, has a remarkably brilliant portion in *Cygnus*, between β and γ, about 90° from the sparse region in *Perseus*. These two characteristic features are evident not only in the distribution of stars of magnitudes 6–9.5[3] but even in the grouping of stars of magnitudes 0–6.[4]

The brilliant region between β and γ *Cygni* is connected—as the photographs abundantly attest—with a smaller but equally bright spot between α and *A* (68) *Cygni*, which in its turn is

[1] *Cf. Ast. Nach.*, No. 3270. [2] *Verslagen Kon. Akademie Amsterdam*, 1892–3.

[3] PLASSMANN, *loc. cit.*

[4] SCHIAPARELLI, "Sulla distribuzione," *Pubbl. Brera*, XXXIV, 1889.

connected with another less brilliant spot, between ρ and π *Cygni*, which is continued by a luminous stream, slightly inclined to the galactic equator, to a kind of knot near η and β *Cassiopeiae*, where the Milky Way divides; in part these branches lose their brightness rather abruptly at the altitude of γ *Persei*. Between *o Cygni*, *a Cephei* and η *Cassiopeiae* a much fainter zone extends, which shows a tendency to reunite with the principal branch.[1] Almost the entire region described here, with a few branches toward *Draco* and *Ursa Major*, and the fairly bright part between β *Cygni* and γ *Ophiuchi*, produce somewhat the impression of an immense appendage of the principal branch, with which the bright region between δ *Cephei* and *a Cygni* would appear to be closely connected; while the series of small luminous spots between γ *Sagittae* and ν *Aquilae* do not seem to be independent of the luminous region north of β *Cygni*.

I insist upon the exceptional position of this spot, or rather conglomeration of bright spots, between β and γ *Cygni*. It lies in the midst of a series of luminous spots and streams between ν *Aquilae* (the series which commences in *Sagittarius* appears to be related to this one) and χ *Persei*, but it is the only one — with the possible exception of the spot at *a–A Cygni*, just on the galactic equator — which is not situated on the inner edge of the principal branch of the Milky Way, but in the secondary zone, not far from the galactic axis. This is, moreover, the only very bright region which occurs in the "secondary zone" (§ 5), and the only place where this zone is brighter than the principal branch.

This region between *A* (68) and β *Cygni* is richer in stars than any other zone in Argelander's *Durchmusterung*. As for the fainter stars, William Herschel found here one of the maxima of his gauges: 588 stars per telescopic field; Th. Epstein[2] counted near ϕ *Cygni* 600 stars to the eleventh or twelfth magnitude in an area which on an average would contain only 140.[3]

[1] EASTON, *Voie lactée;* Boeddicker, *Milky Way*.

[2] See PLASSMANN, *loc. cit.*

[3] The estimate of the brightness of this region in Houzeau's *Uranométrie*, p. 17, is certainly too small.

In the southern hemisphere brighter spots occur, notably that in *Scutum* and near γ and μ *Sagittarii*. But the spot at β–γ *Cygni* is larger than all these others combined. Furthermore, the brightness of the southern region in *Sagittarius* is particularly striking, on account of the contrast between the small bright spots and the very dark regions which separate them; the great bright spot in *Cygnus*, on the contrary, has no definite boundaries and is surrounded by a rather luminous region of the Milky Way.

As for the very faint region in *Perseus*, it is remarkable in that it is situated northeast of the tortuous part of the Milky Way, which, in *Auriga*, deviates considerably from the galactic axis. It may also be remarked that the "zone of nebulae" on Sidney Waters' chart approaches the Milky Way at this same place.

§15. This brilliant and relatively independent region in *Cygnus* which, moreover, is certainly connected with the other parts of the Milky Way, occurs in a part of the sky where, in the provisional supposition made in paragraph 6, the explanation of the general features of the Milky Way would be much simplified if it were permissible to assume the existence of an important stellar condensation in this direction. On the other hand—though this is perhaps a chance coincidence—the center of the secondary accumulation of which our Sun is a part would be situated, according to Professor Kapteyn's investigations, not far from this region.[1]

May not the bright region in *Cygnus* be the *central accumulation of the Milky Way?* If this were the case the general features and many characteristic details of the galactic phenomenon might be easily explained.

Fig. 5 gives an approximate representation of the Milky Way between γ *Ophiuchi* and β *Cassiopeiae* (*cf.* my chart of the Milky Way, Plate IV). Fig. 6 is based upon the two rings of the provisional theory stated in §6. In order to simplify the drawing I have left unbroken the exterior ring $RR'R''$ (principal

[1] KAPTEYN, *Verslagen Kon. Akademie Amsterdam*, 1892–3, p. 129.

branch of the Milky Way) except the very faint part between *R* and *R''* (*Perseus*). As for the interior ring, it must divide into at least three principal parts:

A, the bright part between γ *Ophiuchi* and *Cassiopeia*, considered as an appendage of the principal ring, in accordance with what has been stated in the preceding paragraph.

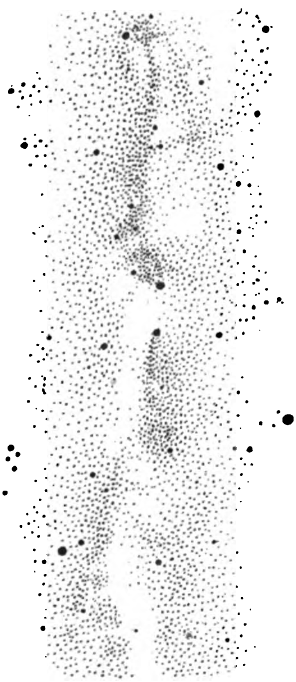


FIG. 5.

B, the secondary branch in *Serpens*, *Scorpius*, *Lupus;* closely related rather to the principal branch in this region than to the secondary branch in *Ophiuchus* (north of γ) and *Cygnus*.

C, the belt of bright stars, projected upon a very faint nebulosity.

Certain details between *Aquila* and *Cassiopeia*, the "luminous bridges" which are projected upon the "rift" between the two branches, etc., have been inserted from the galactic chart of this region (Fig. 5).

The representation of the Milky Way thus obtained curiously resembles the spiral nebulae, of which Dr. Isaac Roberts has given such beautiful photographs.[1] To facilitate the comparison I have sketched in Fig. 7 the principal features of the nebula *M. 74 Piscium*. It is unnecessary to remark that the distortion of the spiral in Fig. 6 is due to the preconceived idea of the two rings (in reality the cluster in *Cygnus*, and not the Sun, is at the center of the system).

From what precedes it follows, furthermore, that the convolutions of this "galactic spiral" would not be situated in a single plane, but principally in two planes forming an angle of about 20°.

[1] *A Selection of Photographs*, London, 1894.

It would be easy to push the comparison further[1] and to find in it a plausible explanation of many features of the galaxy. But I confine myself here to pointing out how easily this theory explains the luminous streams between the two branches of the Milky Way, in *Sagittarius* and *Cassiopeia;* the anomalous brightness of the secondary branch near *Cygnus;* the dark spaces surrounded by luminous streams between *α Cygni* and *β Cassiopeiae*, etc.; the "lateral offsets" of the Milky Way; the connection of the clusters and the bright stars in *Taurus* and *Orion* with the nebulosities related to the Milky Way; the very faint region in *Perseus*, etc.—while retaining the advantages offered by the annular segments. I wish to insist upon the fact that Fig. 6 *does not pretend to give an even approximate representation of the Milky Way*, seen from a point in space situated on its axis. It only indicates in a general way how the stellar accumulations of the Milky Way might be distributed so as to produce the galactic phenomenon, in its general structure and its principal details, as we observe it.

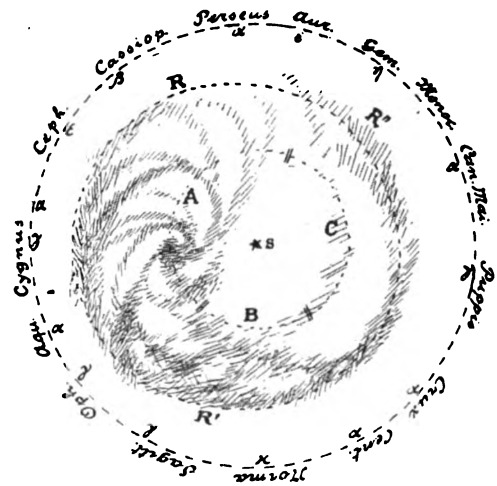


FIG. 6.

[1] Arguments based upon analogy are always dangerous. It is nevertheless permissible to point out here that the most recent observations and photographs show that the spiral is a much commoner form in the structure of nebulae than has hitherto been supposed. Only recently it has been recognized in the supposedly oval nebula of *Andromeda* (*cf.* Scheiner, *Astr. Nach.*, Bd. 148, No. 3549), and Professor J. E. Keeler sums up as follows the results of his investigations on the structure of nebulae (*Astr. Nach.*, Bd. 150, No. 3601): "If, then, numerous exceptions prove that spirality in nebulae is not a universal law, it may perhaps be regarded as the usual or normal accompaniment of contraction in cosmical masses. . . . ."

§16. It is possible that our Sun and the group of stars which, according to the investigations of Schiaparelli, Gould, and Kapteyn, form with it a secondary system in the great galactic system, may be only one of the clusters lost in the convolutions of the galactic spiral. But it seems to me simpler to suppose that what appears to be a "solar cluster" is the expression of the central condensation of the galactic system itself, composed for the most part of suns comparable with our own (and which would thus embrace most of the bright stars to the ninth or tenth magnitude). The distance of the galactic streams and convolutions would then be comparable with the distances of these stars, and there might even exist, at the boundaries of the system, a certain number of very large stars, further from us than most of the stars of the Milky Way. In the galactic convolutions or near them, there would be important stars, of enormous size, centers of stellar condensations exercising a preponderating attraction on the innumerable small stars of the zone, intermixed with nebulosity. Our Sun, lying eccentrically with reference to the convolutions of the Milky Way, would nevertheless not be far from the center of the central condensation of the system, which would be at the same time the central point of the galactic convolutions.

Fig. 7.

Rotterdam,
March 1900.

Minor Contributions and Notes

VARIABLE STARS IN CLUSTERS. RATE OF INCREASE OF LIGHT.[1]

It appears from *Circular* No. 33, that the proportion of stars, found to be variable, in the cluster *Messier 3, N. G. C. 5272*, is greater than in any other object of the same class. This object is, however, so low at Arequipa, and the stars are so faint, that satisfactory photographs cannot be obtained of it, with the 13-inch Boyden refractor, with exposures of less than 90 minutes. The rate of increase of the light of many of these stars is extremely rapid, and in order to determine this change with the greatest precision, photographs having very short exposures are necessary. Accordingly, at my request, Professor James E. Keeler has taken a series of admirable photographs of the cluster with the 3-foot Crossley reflector of the Lick Observatory. These photographs were taken on May 20 and 21, 1900. The first plate had an exposure of 60 minutes, the others, 24 in number, exposures of 10 minutes each. Professor Bailey, from an examination of these photographs, has derived the following results:

Three variable stars have already been measured on these plates. They are Nos. 11, 96, and 119. The series of plates extended from $17^h\ 42^m\ 46^s$ to $20^h\ 24^m\ 11^s$, on the night of May 20, and from $17^h\ 2^m\ 38^s$ to $20^h\ 53^m\ 27^s$, May 21, G. M. T. These periods of time covered the entire interval from minimum to maximum, for each of the above stars, on at least one night. The same stars were also measured on 49 plates made at Arequipa during the years 1895–1899. From a study of all these measures the periods have been determined as follows: for No. 11, $12^h\ 12^m\ 25^s$; for No. 96, $12^h\ 0^m\ 15^s$; for No. 119, $12^h\ 24^m\ 31^s$. For the following discussion of the rate of increase, however, only plates made by Professor Keeler on the night of May 21, and having exposures of 10 minutes were used.

The measures of the brightness of the variables were made by Argelander's method, using a sequence of comparison stars, whose magnitudes have not yet been determined. The results are therefore given in grades. The value of one of these grades is somewhat

[1] *Harvard College Observatory Circular* No. 52.

uncertain, but is not far from one tenth of a magnitude, since in previous work by the same observer the value of one grade was found to be 0.085 of a magnitude. The observations were plotted, using vertical distances to represent magnitudes and horizontal distances, time. A smooth curve was then drawn through them. The time scale employed in the drawing was very open, in order to read with greater accuracy the ordinates of the curve corresponding to intervals of 5 minutes. The results of the measures are very accordant. For all the measures on the Lick plates of 10 minutes exposure, the average deviation from the curve is less than half a grade. The results for the three stars, for the period of increase of the light, are given below. The first column contains the time, and the second, the corresponding brightness expressed in grades. The differences, found by subtracting each value in the second column from that following it, are given in the third column, which therefore represents, in each case, the change in light during an interval of five minutes.

INCREASE OF LIGHT.

Var. No. 11			Var. No. 96			Var. No. 119		
Time	Gr.	Diff.	Time	Gr.	Diff.	Time	Gr.	Diff.
h m			h m			h m		
18 20	0.0	0.0	19 30	0.0	0.0	17 25	0.0	0.0
25	0.0	0.3	35	0.0	0.4	30	0.0	0.6
30	0.3	0.8	40	0.4	1.1	35	0.6	1.0
35	1.1	1.2	45	1.5	1.7	40	1.6	1.2
40	2.3	1.4	50	3.2	2.1	45	2.8	1.4
45	3.7	1.6	55	5.3	2.4	50	4.2	1.5
50	5.3	1.8	20 0	7.7	2.5	55	5.7	1.5
55	7.1	1.9	5	10.2	2.3	18 0	7.2	1.5
19 0	9.0	1.9	10	12.5	1.8	5	8.7	1.4
5	10.9	1.9	15	14.3	1.2	10	10.1	1.3
10	12.8	1.8	20	15.5	0.7	15	11.4	1.2
15	14.6	1.5	25	16.2	0.4	20	12.6	1.2
20	16.1	0.8	30	16.6	0.1	25	13.8	1.0
25	16.9	0.4	35	16.7	0.0	30	14.8	0.9
30	17.3	0.2	40	16.7	..	35	15.7	0.7
35	17.5	0.0	..	....	..	40	16.4	0.4
40	17.5	..	..	....	..	45	16.8	0.2
..	....	..	..	....	..	50	17.0	0.0
..	....	..	..	....	..	55	17.0	..

From this table it appears that the total increase of light, amounting to 17.5 grades, takes place in the case of Variable No. 11 within 70 minutes; in the case of No. 96, an increase of 16.7 grades occurs within 60 minutes; and No. 119, 17.0 grades within 80 minutes. The maximum increase, during any interval of 5 minutes, is, in the case of

No. 11, 1.9 grades; No. 96, 2.5 grades; No. 119, 1.5 grades. During 30 minutes No. 11 increases in light 10.9 grades, or at the rate of 21.8 grades per hour; No. 96, 12.8 grades, or at the rate of 25.6 grades per hour; and No. 119, 8.6 grades, or at the rate of 17.2 grades per hour. The greatest rapidity is in the case of No. 96, which increases, during 5 minutes, at the rate of 30 grades, or at least two and a half magnitudes per hour, and during 30 minutes at the rate of more than two magnitudes per hour. This rate of change appears to be the most rapid of any known variable. The *Algol* variable *U Cephei*, which perhaps undergoes the most rapid change of any star not found in clusters, changes at the rate of about one and a half magnitudes per hour, during the half hour of its most rapid increase and decrease. The total times of increase for the three stars, 70 minutes, 60 minutes, and 80 minutes, are 10, 8, and 11 per cent., respectively, of their entire periods. Near the beginning and end of increase, however, the rate of change seems to be relatively slow. If we allow one and a half grades for each of these periods of slow change, making three grades in all, we find that the remaining increase, amounting to more than four fifths of the whole change in light, takes place for the three stars in 42 minutes, 34 minutes, and 54 minutes, respectively, that is, in about 6, 5, and 7 per cent. of the respective full periods. In the case of No. 96, this increase is about ten times as rapid as the corresponding decrease. In general it may be stated that the length of periods and the form of light curves are similar to those of many of the variables in *Messier 5*, and in *ω Centauri* (ASTROPHYSICAL JOURNAL, **10**, 255). It will be noted that the periods of these three stars in *Messier 3* are about one half a day. Several other variables in this cluster appear to have approximately the same period.

EDWARD C. PICKERING.

June 18, 1900.

THE YERKES OBSERVATORY OF THE UNIVERSITY OF CHICAGO.

BULLETIN NO. 15.

PHOTOGRAPHS OF STAR CLUSTERS MADE WITH THE FORTY-INCH VISUAL TELESCOPE.

THE objective of the 40-inch telescope is corrected for visual observations, the minimum focus corresponding to about λ 5800. The color curve is very steep from λ 4800 toward the violet, and the difference

in focus between D and K amounts to about 130 mm.[1] It is thus eminently unsuited for photographic work with ordinary plates sensitive to blue light. The expedient of providing a third lens, of large aperture, to be placed in front of the 40-inch objective for the purpose of uniting the blue rays in a common focus, although successfully employed in the case of the Lick telescope, was not adopted for several reasons. The principal objections to such a correcting lens include its great weight and cost; the serious increase in absorption for the shorter wave-lengths; and the inconvenience arising from the change of focus, which brings the focal plane of the triple combination far up in the tube. Small correcting lenses, placed near the principal focus, have been employed with excellent effect in photographing the more refrangible regions of stellar spectra. On account of the small field of such lenses they cannot be used to photograph large groups of stars. In solar photography with the spectroheliograph, although violet light is employed, no difficulty is experienced from the steepness of the color curve, because the sensitive plate is exposed to a single line in the spectrum, and shielded from all other radiations. It remained, however, to perfect a method by which the advantages arising from the great focal length and high separating power of the 40-inch objective could be realized in direct stellar photography.

In 1892, while photographing the Moon with the 12-inch telescope at the Kenwood Observatory, Mr. G. W. Ritchey suggested that the 40-inch Yerkes telescope, then in process of construction, could probably be used to advantage for similar work. In an article on astronomical photography published about that time he explained the use of a color screen, in immediate contact with the plate, for cutting out the more refrangible rays, and pointed out that isochromatic plates, then only recently obtainable in commerce, should in large measure compensate for the loss of blue light. In 1897 some excellent photographs of the Moon were obtained by Mr. Ellerman and the writer with the 40-inch telescope, using a thin yellow screen in front of isochromatic plates.[2] These photographs are very sharp, and compare favorably with negatives taken with the Lick telescope and 33-inch correcting lens. The investigation could not be continued at that time, on account of the pressure of other work. So far as is known no attempt has hitherto been made to utilize a visual telescope in this way for

[1] See this JOURNAL, 10, 94, 1899.

[2] First Annual Report of the Director of the Yerkes Observatory, p. 9.

PLATE XVIII

PHOTOGRAPH OF THE CLUSTER *MESSIER 13*

TAKEN WITH THE 40-INCH YERKES TELESCOPE BY G. W. RITCHEY

photographing faint objects, such as the fainter stars, star clusters and nebulæ.

This work has recently been taken up by Mr. Ritchey with the 40-inch telescope, and he has already obtained excellent results. Special color screens of thin plate glass, coated with very transparent collodion of a delicate greenish-yellow tint, were prepared under his direction by the Carbutt Dry Plate Company. Short exposure photographs of stars, made on isochromatic plates in immediate contact with the absorbing screen, were so successful as to show beyond doubt the feasibility of photographing faint stars with long exposures. A special plate-holder, provided with screws for moving the plate with guiding eyepiece in two directions at right angles to each other, was designed by Mr. Ritchey, and constructed in our instrument shop under his supervision. As the apparatus was intended primarily for experimental purposes, and especially for photographing star clusters, a yellow screen only three inches square (about 14′ of arc) was employed. The guiding eyepiece (power about 1000) which is used in conjunction with a right-angle prism, stands just beyond the edge of the sensitive plate. It is supported on a slipping piece, and can be moved in two directions so as to permit a suitable guiding star to be found. In its focal plane are two fine cross-hairs intersecting at right angles, and illuminated by a small incandescent lamp controlled by a rheostat. In the exposures so far made no difficulty has been experienced in guiding with a twelfth magnitude star.

Plate XVIII is a reproduction (enlarged 22 diameters) of a photograph of the great cluster in *Hercules*, *Messier 13*, obtained by Mr. Ritchey on August 9, 1900, with an effective exposure of ninety minutes. The original negative shows by actual count about 3200 stars, a large proportion of which are lost in the reproduction. In spite of the fact that the Moon was nearly full, and that a part of the exposure was made through passing clouds, the plate was but little fogged after a half hour's development. The diameter of the smallest stars does not exceed one second of arc, and faint double stars of but little more than 1″ distance are clearly separated. With such excellent definition, and in view of the fact that stars as faint as the sixteenth magnitude appear on the plate, it is evident that the 40-inch telescope with this inexpensive attachment may fairly be regarded as a very efficient photographic instrument. As there is no reason to doubt that fields fifteen inches square can be photographed with a larger plate-holder, it appears

probable, from Mr. Ritchey's results, that the large telescope will henceforth be available for all classes of stellar photography. The large scale of the photographs and the small diameter of the images render the plates of great value for purposes of precise measurement.[1]

Yellow absorbing screens have been tried before with visual telescopes for lunar photography, but it does not appear that the advantages of the method have been appreciated. Mr. Ritchey's combination of a special color screen with an isochromatic plate and an efficient guiding device has yielded results which should encourage the use of other large visual telescopes for photographic investigations.

GEORGE E. HALE.

August 10, 1900.

COMPARISON OF A PRISM AND A GRATING SPECTROSCOPE.

IN considering the refraction of light the question arises as to whether it requires time for the medium to reach a steady state; *i. e.*, whether a short train of waves is refracted in the same way as a long train of the same period. As an attempt to answer this question Professor Henry A. Rowland suggested that Dr. A. W. Ewell and I should adjust a plane grating spectroscope and a prism spectroscope with a long train of prisms, so that we could examine the spectrum of the same source in each instrument; then adjust the slit so that when the source is continuous (*e. g.*, an arc lamp) the spectrum is as nearly as possible the same in both instruments; then replace the arc by a very quick spark and again compare the spectra. If the initial disturbance is refracted differently from a continuous one, then in the second case the lines as seen in the prism instrument should be broadened or rendered hazy on one or both sides as compared with the same lines in the grating spectroscope.

We used a small plane grating and a two-story Grubb spectroscope with an equivalent train of ten 4½ cm sixty-degree prisms, whose index of refraction for the D lines was about 1.6; and we examined the *b* group of lines, where the dispersions of the two instruments were nearly the same. Owing to the faintness of the spark spectrum as given by the Grubb instrument the results are unsatisfactory; but we

[1] It will, of course, be necessary to investigate the possible effects of distortion arising from the use of the color screen.

saw not the slightest effect. The total duration of the light from each spark of the specially constructed condenser was about 10^{-7} seconds, as measured with a rotating mirror. While this is too short to give sufficient light, it is probably much too long to render the effect sought visible, even under good conditions.

The faintness of the spectrum given by the Grubb spectroscope as compared with that of the grating was so surprising that it seemed advisable to make a rough comparison of the relative efficiencies of the two instruments. By the efficiency of a spectroscope I mean the ratio of the product of the intensity of the spectrum by its width to the total amount of light striking the first prism, or grating, as the case may be. Adopting this definition, it was found that for a continuous spectrum of moderate intensity the grating spectroscope is in the red four, in the yellow five, in the green six, and in the blue eight times as efficient as the Grubb instrument.

N. ERNEST DORSEY.

JOHNS HOPKINS UNIVERSITY,
May 1900.

NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric, and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right, unless the author requests that the reverse procedure be followed. If a request is sent *with the manuscript* one hundred reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

The Editors do not hold themselves responsible for opinions expressed by contributors.

The ASTROPHYSICAL JOURNAL is published monthly except in February and August. The annual subscription price for the United States, Canada, and Mexico is $4.00; for other countries in the Postal Union it is 18 shillings. Correspondence relating to subscriptions and advertisements should be addressed to *The University of Chicago, University Press Division, Chicago, Ill.*

Wm. Wesley & Sons, 28 Essex St., Strand, London, are sole foreign agents, and to them all European subscriptions should be addressed.

All papers for publication and correspondence relating to contributions and exchanges should be addressed to *George E. Hale, Yerkes Observatory, Williams Bay, Wisconsin, U. S. A.*

THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOL. XII — OCTOBER, 1900 — NO. 3

The ASTROPHYSICAL JOURNAL is published monthly except in February and August. Annual subscription, $4.00; foreign, 18 shillings. *Wm. Wesley & Son, 28 Essex Street, Strand, London*, are sole foreign agents and to them all European subscriptions should be addressed. All papers for publication and correspondence relating to contributions and exchanges should be addressed to *George E. Hale, Yerkes Observatory, Williams Bay, Wisconsin, U. S. A.* All correspondence relating to subscriptions and advertisements should be addressed to *The University of Chicago Press, Chicago, Ill.* All remittances should be made payable to the order of the *University of Chicago.*

[Entered at the Post Office at Chicago, Ill., as second-class mail matter.]

THE
ASTROPHYSICAL JOURNAL
AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME XII OCTOBER, 1900 NUMBER 3

ON THE ARC-SPECTRA OF SOME METALS, AS INFLUENCED BY AN ATMOSPHERE OF HYDROGEN.

By HENRY CREW.

THE orderly arrangement of lines in the arc-spectra of metals belonging to the first and second groups of Mendelejeff's table and the apparent disorder among the lines of the remaining groups constitute one of the most striking features of spectroscopic science in its present state. That this disorder is only apparent is evident not alone on *a priori* grounds but also from the fact that, among these very elements, many pairs and groups of lines with constant frequency-differences have been discovered.

One great barrier to the discovery of more complete order in these spectra is the enormous number of lines with which the metals of these groups are burdened.

In order to simplify matters the first step would, therefore, appear to be the discovery of some basis upon which the spectral lines of any one element might be separated into smaller divisions. Such an analysis would at least greatly increase the chances of finding new series.

Such a basis of division has already been hinted at by Kayser,[1] who found that nearly two thirds of all the reversed lines of palladium were arranged in triplets having the same frequency-differences. In short, reversibility appears to be a distinguishing feature of a group of palladium lines whose law of distribution is yet unknown.

It occurred to the writer that possibly another basis of division might be found in the effects produced by surrounding the arc with various atmospheres of gas, as, for instance, hydrogen, nitrogen, coal gas, ammonia.

The experiment[2] with hydrogen was tried as follows: An arc was operated between two metallic electrodes, one of which was in rapid rotation while the other was fed in slowly by means of a screw.

This arc, including the rotating electrode, was placed in a brass hood which was made of two parts, not unlike the Magdeburg hemispheres, except that these two hemispheres, instead of having flat faces, were threaded with a screw and provided with accurately turned flanges, so that, when closed, the hood was gas-tight.

Into one of these hemispheres were fitted the two electrodes, one by means of a gas-tight bearing, the other by means of a gas-tight nut-and-screw. It was necessary, of course, to insulate at least one of these electrodes from the brass hood: this was done by placing the nut-and-screw on a slate plate, which in turn was screwed to the brass hood. The shaft which carried the rotating electrode and the current could, therefore, touch the brass hood with impunity; but, as a matter of fact, this was not the case. On the contrary, the shaft fitted loosely into a bearing which was packed with clean asbestos. This packing served not only the purpose of insulation but also to prevent any oil reaching the interior of the hood. Consequently

[1] KAYSER: "Bogen-spectra der Elementen der Platin-gruppe." *Abh. Berl. Akad.*, 1897, p. 42.

[2] The entire apparatus described below and the experiments depending upon it were made possible only through the generous consideration of the committee of the American Academy of Arts and Sciences in charge of the Rumford Fund.

no hydrocarbons were formed at the arc unless from carbon impurities in the electrodes themselves.

On the side opposite the arc, the hood was provided with an opening into which screwed a brass tube about one foot long. At its outer end, this tube carried an image-lens of quartz, which projected the arc upon the slit of a 10-foot concave Rowland spectrograph.

The hydrogen was furnished by three large electrolytic cells, made with sheet-lead electrodes in dilute sulphuric acid. Each cell absorbed twelve amperes of current, so that the hydrogen produced by thirty-six amperes was continually flowing through the hood. This hydrogen, which was introduced through a stop-cock on one side, was allowed to escape through a stop-cock on the opposite side of the hood, where it burned continuously as a pilot flame about two centimeters high. In the current of hydrogen a trap, instead of a drying tube, was used, for it was found by experiment that there was no difference in effect between hydrogen which had been dried by phosphorus pent-oxide and sulphuric acid, and hydrogen which had not been dried at all.

The most marked effect of hydrogen on the arc-spectrum is a general diminution of intensity. Consequently, in order to photograph the spectrum of the arc *in hydrogen* so as to give, on the negative, an average intensity equal to that of the arc *in air*, one must make the exposure in hydrogen from 5 to 100 times as long as in air.

The most interesting effect of the hydrogen atmosphere, however, is not the change in the average intensity of the entire spectrum, but the change of relative intensity among the lines of any one substance. This change was studied by photographing on each negative three spectra side by side. The first was that of the arc in air, the second that of the arc in hydrogen, the third that of the arc in air. But the exposure was always so timed that the spectrum in hydrogen had an intensity which was intermediate between the two intensities in air. The advantage of this is that, in comparing intensities, if a line is apparently

weakened one has a still weaker spectrum with which to compare it, and hence can decide whether the weakening is due to under-exposure or due to some effect on this particular line and not on the whole spectrum. In like manner, if a line is apparently intensified, one has a still stronger spectrum with which to compare it, and to convince himself that the intensification is not due to over-exposure.

The effects of hydrogen on the spectra of magnesium and zinc are partially summarized in Tables I and II, which follow.

TABLE I.

ARC-SPECTRUM OF MAGNESIUM AS MODIFIED BY AN ATMOSPHERE OF HYDROGEN.

Wave-length of lines which are relatively			Remarks
intensified	weakened	unaffected	
		5711.31	
		5528.64	
		5183.79	
		5172.86	Second subordinate series: Kayser and Runge.
		5167.50	
	[5007.47]		First head of magnesium-oxide fluting. This and the six following bands are, of course, completely blotted out.
		4730.42	Line too weak to compare.
		4703.18	Widened towards red.
	4571.28		Intensity halved.
4481.			Intensity increased perhaps ten times: line enormously widened. This line does not appear in the ordinary carbon-magnesium arc.
		4352.08	Widened towards red.
	[4216.12]		Cyanogen, Band II, which appears as an impurity: is completely blotted out, owing to absence of nitrogen.
		4167.81	
		4058.45	
		3987.08	
	[3883.55]		Cyanogen, Band III: impurity: completely blotted out.
		3838.44	
		3832.45	First subordinate series: Kayser and Runge.
		3829.50	
	[3590.48]		Cyanogen, Band IV: does not quite disappear.
		3336.82	
		3332.33	Second subordinate series.
		3330.04	

TABLE I.—*Continued.*

Wave-length of lines which are relatively intensified	weakened	unaffected	Remarks
		3097.01	First subordinate series.
		3093.09	
		3091.18	
		2942.21	Second subordinate series.
		2938.67	
		2936.99	
2936.61			Strong spark lines.
2928.74			
		2915.57	
	2852.22		Strong spark line: width of reversed portion increased at least ten times: line, as a whole, nearly extinguished.
		[2852.22]	First subordinate series. From analogy, the first line of this triplet, here covered by the heavy spark line, is probably unaffected by hydrogen.
		2848.53	
		2846.91	
		2802.80	Reversal greatly increased.
		2798.07	
		2795.63	Reversal greatly increased. A second reversal, not occurring in the ordinary arc, appears in the shade of this line at 0.7 tenth-meters towards the violet.
		2790.88	
		2783.08	
		2781.52	
		2779.94	Width and reversal increased.
		2778.38	
		2776.80	
	2768.57		

The line at 2765.47 and the five triplets of still shorter wave-length which complete Kayser and Runge's list of magnesium lines are so completely blotted out by the hydrogen atmosphere that no comparison in this region is possible — even on plates of four hours exposure. And this is true while many sharp lines, impurities, of shorter wave-length yet appear on the negative.

TABLE II.

SPECTRUM OF ZINC ARC AS MODIFIED BY AN ATMOSPHERE OF HYDROGEN.

Wave-lengths of lines which are relatively			Remarks
intensified	weakened	unaffected	
5182.20			
		4810.71	Second subordinate series.
		4722.26	
		4680.38	
	4630.06		Shading towards red greatly increased.
	4298.54		Too faint to compare with certainty; apparently weakened.
	4293.02		
	4101.94		
	[3683.63]		Two very persistent lead lines which, as impurities, are greatly weakened by hydrogen.
	[3679.72]		
		3315.26	Not strong enough for comparison.
		3346.04	
		3345.62	First subordinate series.
		3345.13	
		3303.03	
		3302.67	
		3282.42	
	3075.99		
		3072.19	Second subordinate series.
		3035.93	
		3018.50	
		2801.00	
	2781.33		
		[2771.05]	Not found.
		2770.94	
		2756.53	
		[2751.49]	No trace of these lines in hydrogen.
		[2736.96]	
		2712.60	Second subordinate series.
		2684.29	
		2670.67	
		2623.87	Invisible in hydrogen.
		2608.65	Last triplet visible on hydrogen negative after two hours exposure.
		2582.57	
		2570.00	
2558.03			Strong spark lines: shortest wave-length visible on hydrogen negative after two hours exposure.
2502.11			

The lines 2601.03, 2575.15, 2562.70, 2138.03, and the remaining six triplets of Kayser and Runge, could not be obtained in the hydrogen atmosphere under any reasonable exposure.

THE IRON SPECTRUM.

In the case of iron, the number of spectral lines is so enormous that we can here merely illustrate the effects of a hydrogen atmosphere by giving the principal changes which occur in the region covered by a single negative.

In the first column of the following table is given the wave-length of the line. These wave-lengths are reliable to about 0.05 of an Ångström unit. The second column gives the intensity of the line in the atmosphere of hydrogen. The scale of intensities runs from "1" for lines just easily visible, to "10" for the heavy lines. In the third column is given the effect produced by hydrogen. Here the word "*new*" is used to indicate that the line does not appear in the ordinary iron arc. "*Enh*" is a contraction for the word "enhanced," and the number which follows "*Enh*" indicates, roughly of course, how many times greater the intensity is in hydrogen than in air. The term "*Dim*" is a contraction of "diminished," and the number following indicates how many times weaker the line is in hydrogen than in air.

The illustrations given are sufficient to show that the hydrogen atmosphere does more than slightly alter these spectra: it profoundly modifies them.

The explanation of these changes is probably simple, but it is not patent. A number of hypotheses thrust themselves upon one's attention, but as a rule they are difficult to test by experiment, and their value is, therefore, not great. For instance, it does not appear impossible that the resistance of the arc may vary considerably with the nature of the atmosphere surrounding it; and, if so, then the temperature and the spectrum may vary. But whether, in such case, the hydrogen would serve to increase or diminish the temperature it is not easy to predict.

In nearly all the spectra which I have photographed an average direct current of about 2 amperes has been employed, while the pressure between the electrodes has varied from 75 to 100 volts. The current was constantly varying in intensity and was often completely interrupted. Is it not possible that an

TABLE III.

ILLUSTRATION FROM SPECTRUM OF IRON ARC IN HYDROGEN.

Wave-length	Inten-sity	Description	Wave-length	Inten-sity	Description
4056.13	8	New	3666.95	7	Enh 8
4039.03	7	New	3660.76	2	New
4027.27	8	New	3659.09	7	Enh 20
4000.12	6	New	3652.50	3	Enh 10
3997.16	10	Enh 10	3652.22	3	Enh 10
3944.54	7	Enh 10	3648.52	3	Enh 8
3941.02	1	Dim 7	3645.24	6	Enh 10
3938.37	4	New	4643.78	2	Dim 2
3928.74	4	Enh 6	3642.67	4	New
3926.57	8	Enh 4	3630.46	1	Dim 2
3920.91	10	Enh 7	3626.90	3	New
3917.97	10	Enh 8	3625.27	2	Dim 2
3910.79	10	Enh 10	3620.07	8	Enh 10
3906.61	2	Dim 5	3616.71	7	Enh 5
3899.85	3	Dim 4	3615.88	7	Enh 5
3899.19	12	Enh 6	3612.20	1	Dim 4
3898.09	5	Dim 2	3607.44	7	Enh 10
3897.61	8	Enh 3	3602.60	2	Dim 2
3889.31	5	New	3598.94	8	Enh 8
3866.97	5	Enh 10	3594.68	3	Dim 3
3864.28	5	Enh 5	3593.55	6	Enh 3
3861.66	5	New	3583.92	6	Enh 10
3850.48	4	New	3573.15	5	Enh 5
3843.93	8	Enh 6	3572.06	2	Dim 2
3825.13	4	Enh 10	3540.53	3	Enh 10
3814.63	1	Dim 4	3538.76	5	Enh 10
3807.64	2	Dim 5	3507.15	5	Enh 10
3801.79	8	Enh 4	3499.34	4	Enh 10
3800.57	8	New	3493.60	4	New
3790.23	3	Dim 2	3491.22	3	Enh 4
3786.82	1	Dim 4	3474.19	2	Enh 4
3781.79	3	New	3465.98	4	Dim 2
3775.81	3	New	3460.43	2	Enh 4
3771.71	5	New	3323.20	2	New
3767.78	6	Enh 10	3281.40	2	New
3759.28	3	Enh 8	3277.55	3	Enh 5
3739.98	10	Enh 10	3274.09	1	Dim 5
3724.09	4	Enh 8	3265.17	0	Dim 6
3723.30	4	Enh 8	3264.64	0	Dim 4
3718.04	3	New	3259.17	6	New
3706.16	3	Enh 10	3258.89	4	New
3700.36	4	New	3257.70	2	Dim 2
3692.92	5	New	3251.36	0	Dim 5
3692.08	5	Enh 12	3247.67	1	Dim 6
3688.29	6	Enh 10	3246.13	0	Dim 10
3683.19	3	Dim 3	3243.87	2	Enh 4
3680.08	4	Dim 2	3237.95	2	New
3671.78	2	Enh 4	3236.35	1	Dim 8
3668.50	6	Enh 7	3234.75	0	Dim 10

atmosphere of hydrogen increases the rapidity of these interruptions, and hence alters the effects of self-induction, thereby changing the temperature of the arc?

Still a third hypothesis is that the introduction of hydrogen prevents the formation of oxygen and nitrogen compounds, thus blotting out some lines, and that it permits the formation of hydrogen compounds, thus accounting for the appearance of new lines.

Whatever the explanation may be, the following curious relation was found to exist between the arc- and spark-spectra, namely, *all lines in the arc-spectrum which are affected by hydrogen, whether enhanced or diminished, belong to the spark-spectrum also.*

To illustrate: the arc-spectrum of tin in hydrogen shows two strong lines at λ 3362.15 and λ 3283.31, of which there is not the faintest trace in the ordinary tin arc. But these two are among the strong lines of the tin spark. See Hartley and Adeney's list. In like manner I have photographed on the same plate the iron spark in air, the iron arc in air, and the iron arc in hydrogen. In every case examined, the lines affected by hydrogen are spark lines.

On the other hand, *the lines which belong to Kayser and Runge's series are unaffected by the change from air to hydrogen.* If these series prove equally stable in other gases, this stability may form a criterion for dividing a spectrum into two groups, one of which will contain all the series lines, the other of which will contain none of them.

NORTHWESTERN UNIVERSITY,
Evanston, Ill.

SOME ABNORMAL STARS IN THE CLUSTER *M 13 HERCULIS.*

By E. E. Barnard.

For a long time I have been engaged in a micrometrical determination of the positions of a number of the individual stars in the great globular clusters *M 3*, *M 5*, *M 13*, *M 15*, and *M 92*.

In this work several peculiarities have come up that have seemed of importance. The most striking of these is the fact that some of the stars in these clusters shine with a much bluer light than the great majority. This produces a most remarkable difference between their photographic and visual images. In comparing photographs with the actual sky one is often struck with the relative smallness of certain stars on the photographs that are bright in the sky. This peculiarity is due to more or less color in these stars which produces a smaller photographic image. This is sometimes so pronounced that it is troublesome to identify the individual stars.

What one finds in the clusters is just the reverse of this, *i. e.*, certain of the stars appear very much larger on the photographs than they do in the sky. So striking is this in some cases as to at first suggest variability.

This peculiarity was noticed among the first observations of the clusters made here, and attention was called to it at the meetings of astronomers at Harvard College Observatory in 1898, and at the Yerkes Observatory in 1899.

The comparisons were made with a negative enlarged about four times from the original photograph of *M 13 Herculis*, taken with the Potsdam 13-inch photographic refractor in 1891, which was measured by Professor Scheiner for his catalogue of 833 stars of this cluster. This photograph was kindly loaned me by Professor Frost, who assisted Professor Scheiner in his work on the cluster.

The most striking of these photographically bright stars in *M 13* are Nos. 148, 179, 382, 393, and 749 of Scheiner's catalogue. The brightest of these is No. 148, which is also perhaps the most striking example. Since this star is an outlier, it is conspicuous on all photographs of the cluster. On the Potsdam and other photographs it is the brightest star belonging to the cluster. It several times outranks all the stars near it in brightness, and stands out conspicuously above all its neighbors. North preceding it about 19″, is the star No. 131; on the photograph this last star appears very small and inconspicuous, compared with 148. In the sky, however, they are almost identical in brightness, though on the photograph 148 is four or five times larger. Some 68″ following, and south, is No. 269, which on the photograph appears four or five times smaller than 148, but somewhat larger than 131. In the telescope No. 296 is nearly one magnitude brighter than 148. Yet 131 and 296 and their surrounding stars bear the same light ratios in the sky that they do on the photograph, No. 148 being alone photographically abnormally bright. This star was tested with a high magnifying power to see if it came to a focus different from the stars near it, but there did not seem to be any difference in this particular. It was seen, however, that the image of 148 did not, under the best conditions, appear as sharp as the stars near it; it gave the impression of a slight fuzziness; at such times it has suggested the idea of a minute nebula, or rather of a minute planetary nebula. The magnitude of this star as given by Scheiner is 11.7, making it the brightest star with one exception (that of a more distant outlier, also 11.7) of any in the cluster. The two other stars, 131 and 296, are rated respectively as $12^{m}.7$ and $12^{m}.4$.

No. 382 is Scheiner's normal star, and is assigned magnitude 12.7; visually it cannot exceed $14^{m}.5$ and is very much fainter than other stars which match it on the photograph.

No. 749 is visually exactly equal to No. 763, but on the Potsdam photograph it is three or four times larger than the latter star.

No. 393 is very difficult to see at all, though it is assigned magnitude 12.7 and on the photograph appears as large as other stars near it which immensely outshine it in the telescope. It is the most striking example of faintness, visually, of these stars. Yet the majority of the stars on the photographs bear the same relative size to each other that they do in the sky. The phenomenon is therefore an exceptional feature, pointing to something remarkable in these particular stars not possessed by the great majority of stars in the cluster.

No. 179 is a striking case because of its close proximity to a star of normal condition, No. 183. On the photograph they are almost exactly equal, while in the sky 179 is many times smaller (about $14^{m}.5$ to 15^{m}) and very faint. There are really two small stars at this place, close together, the preceding one of which is slightly the brighter. Of these two small stars the photograph shows that the peculiarity lies only in the preceding star. The position of the brighter one with reference to 183 is

$$207^{\circ}.0 \quad 7''.78.$$

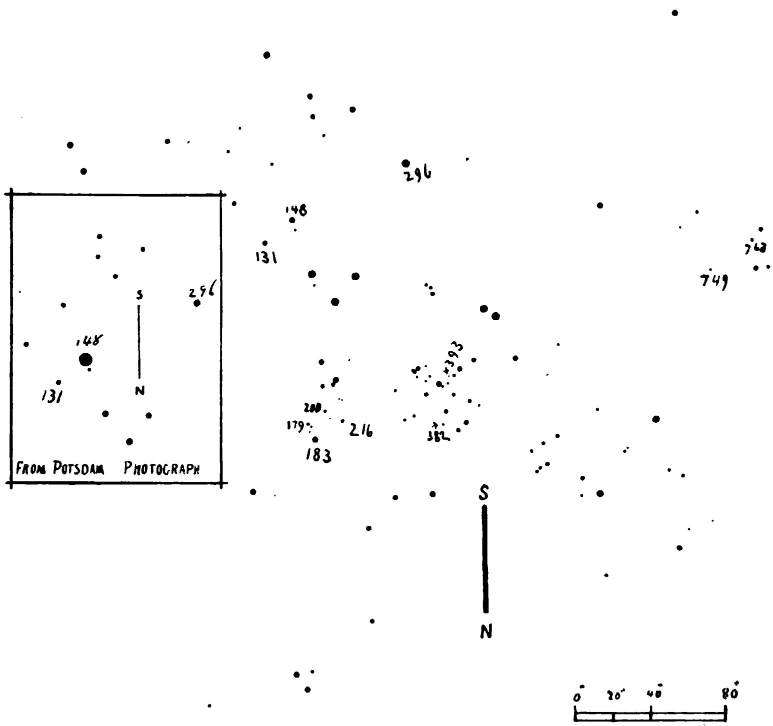
The star 216, which is shown to be variable with the 40-inch, seems also to be abnormal—because on the Potsdam photograph it appears considerably brighter than 183, which it never equals visually.

The accompanying diagram will show the location of the stars referred to. The small diagram from the Potsdam photograph shows the relative size of the abnormal star 148 compared with the stars near it, while the larger diagram gives its appearance as seen in the telescope. The star 393 is in the heart of the cluster. It will be easy to identify any of these stars on photographs of the cluster that show them. They are platted from the micrometer measures.

Of course the simple explanation of this peculiarity is that these stars, so bright photographically and so faint visually, are shining with a much bluer light than the stars which make up the main body of the cluster. This is an interesting fact, and would seem to be an important one.

This peculiarity does not exist alone in *M 13*, for I have found similar cases in *M 5 Librae*, and it doubtless exists in the other clusters.

Speaking with Professor Hale a short time ago on the subject, he suggested that a photograph made with a yellow color-



screen ought not to show this peculiarity, and that the stars on such a photograph should be closely comparable with the visual appearance. A photograph of *M 13* made the next night by Mr. Ritchey with a yellow color-screen on the 40-inch showed that this statement was correct, for on this picture 148, 382, 179, etc., appeared with the same relative brightness that they have in the telescope.

It would be an interesting thing to know just what these abnormal stars are. At present the spectroscope is unable to deal

with such faint objects. The fact remains, however, that we have in the globular clusters, relatively, a few stars which differ widely from their fellow stars in the same cluster, and which seem to shine with a strong blue light, resembling in this respect the nucleus of the annular nebula of *Lyra* (*M 57*) and perhaps bearing the same relation to the ordinary stars of the cluster that the nucleus of that nebula bears to the ordinary stars of the sky.

As bearing on the possible existence of minute nebulæ in the clusters, I have found a very small nebula preceding *M 15* which, if much smaller, would be taken for an ordinary star. It is 13th magnitude and by micrometer measures is $2'.1$ in extreme diameter. It appears as a very small hazy star which, with the higher powers, is seen to be an extremely small nebula. It precedes the center of the cluster by $1^m\ 7^s$ and is $1\frac{1}{2}'$ north. Its position for 1860.0 is therefore $\alpha = 21^h\ 22^m\ 6^s, \delta = +11°\ 34'.8$.

Position of the nebula with reference to $13^m.5$ star (s. of 2) 1899 Aug. 15: P. A. $220°.4$, Dist. $28''.48$. The nebula and the two small stars lie midway between two $12^m.8$ stars which are $5'$ apart. The double star whose measures are given below follows the nebula by $13^s \pm$ and is about $1\frac{1}{4}'$ north.

Closely preceding the cluster is what seems to be another very minute nebula, but I could never be certain that it is a nebula—it is so small. It is 14^m and precedes the center of *M 15* by $5'$ and is $1'$ north.

Small double star $0^m\ 52^s$ preceding and $2'$ north of the center of *M 15*:

(Approximate position 1900.0: $\alpha = 21^h\ 22^m\ 21^s$, $\delta = +11°\ 34'.9$)

1898.610	Aug. 10	$62°.5$	$0''.97$		
1899.623	Aug. 15	60.7	0.92	$12^m.5$	$13^m.5$
1899.738	Sept. 26	61.7	1.08		
1899.32		$61°.6$	$0''.99$		

This is a new double star.

The possibility of these abnormal stars being of the nature of nebulæ brings up the question of nebulosity in the globular clusters. In the observations here, sometimes under very fine

conditions, I have become convinced that the great clusters are not nebulous, as has been claimed from insufficient evidence, and this confirms my observations made with the 36-inch at the Lick Observatory.[1] Under the best conditions there is no appearance of true nebulosity. Professor Keeler has lately shown from photographs with the Crossley reflector that there is no evidence of nebulosity even from a photographic standpoint.

YERKES OBSERVATORY,
August 1900.

[1] See *Monthly Notices*, November 1896, **57**, 11–12.

DISCOVERY AND PERIOD OF A SMALL VARIABLE STAR IN THE CLUSTER *M 13 HERCULIS.*

By E. E. BARNARD.

WHILE engaged in micrometrical work on the stars in the great globular clusters, I have become deeply interested in the variable stars found by Professor Bailey on his photographs of these objects taken at Arequipa, and a large number of observations of some of these stars has been secured and will be printed with the micrometrical work when it is issued.

The great cluster of *Hercules*, *M 13*, at first seemed to differ from the other globular clusters in having no variable stars within its boundaries. This seemed to be the case as late as 1898. About that time, however, Professor Bailey found two stars slightly variable among the outliers on the Harvard photographs. I have simply heard that such were found, but have seen nothing stated as to their position in the cluster so that they might be identified and observed. I therefore do not know of the location of any such variables, and have made no special search for such stars. During the micrometer measures, however, I have found a variable star just within the edge of the brightest part of the cluster.

This star was found entirely through the visual observations and not from an examination of photographs. Indeed, the only photograph that I had seen up to the time of finding it that showed the star at all was the Potsdam photograph. Its region is burned out in the other pictures by over-exposure. I have identified it as No. 216 of Scheiner's catalogue of stars measured on a photograph of *M 13*. Its position has been micrometrically measured with reference to other stars of the cluster.

Scheiner Nos. 205 and 216,

$14^\circ.12$ (2) $21'.49$ (2).

Scheiner Nos. 183 and 216,

$129^\circ.53$ (4) $17'.50$ (4).

Scheiner Nos. 373 and 216,

$288^\circ.45$ (2) $55'.16$ (2).

The variation is about one entire magnitude, from the 13th to the 14th, or rather from the 14th to the 13th, because its normal condition is faint.

From observations covering an interval of 70 periods, from 1899, August 14, to 1900, August 7, I deduce a period of 5 days, 2 hours, and 24 minutes ($5^d.10$). From approximate elements its light curve seems to be much like the ones found by Professor Bailey for the variables in *M 5 Librae*. The rise in brightness is rapid and the decline relatively slow. The star takes about 1 day to rise to its maximum, and its decline occupies about 2½ or 3 days. The rise is therefore about 0.2 and the decline about 0.5 or 0.6 of the entire period.

The photographic magnitude given this object star by Professor Scheiner is 12.4. I have compared the light of the variable with No. 200 near and preceding it.

Following are the observations:

COMPARISON OF THE LIGHT OF THE VARIABLE (NO. 216) WITH NO. 200.

(Time 6 hours slow of Greenwich.)

1900, July	9	$0^m.2$	brighter than No. 200 at	$11^h 35^m$.
	10	0 .1		11 10
	10	0 .4		14 0
	11	1 .0		9 40
	12	0 .7		10 10
	24	0 .1		10 0
	24	0 .1		12 25
	25	0 .1		9 15
	25	0 .0		10 20
	26	0 .7		12 0

1900, July 28	$0^m.3$ brighter than No. 200 at	9^h	15^m.
29	0 .1	9	10
29	0 .1	10	55
30	0 .0	9	45
30	0 .1	12	0
31	0 .7	8	50
31	0 .7	10	10
Aug. 1	1 .0	10	10
4	0 .1	8	15
5	0 .7	12	0
6	1 .0	8	35
7	0 .5	8	15
12	0 .5	8	35
13	0 .1	8	50
14	0 .0	8	5
18	0 .1	8	25
20	0 .1	8	00
21	1 .0	8	40
27	0 .6	7	35
28	0 .3	9	00
Sept. 3	0 .1	7	20
3	0 .2	7	50
4	0 .1	7	15
4	0 .2	8	0
19	0 .2	10	10
Oct. 2	1 .0	6	40

This star was also at its maximum on August 14, 1899. For purpose of identification, it is marked on the accompanying chart.

YERKES OBSERVATORY,
August 1900.

SOLAR PHENOMENA, CONSIDERED IN CONNECTION WITH ANOMALOUS DISPERSION OF LIGHT.[1]

By W. H. Julius.

The rule that the propagation of light is, in all directions, rectilinear, holds only for quite homogeneous media. If various considerations lead us to assume that the solar rays on their course penetrate media of unequal density, or of different composition, the rays must be curved, and the supposition that the observed light is emitted by objects situated in the direction of vision becomes untenable.

Now, though no one doubts the unequal distribution of matter in and near the Sun, yet in theories concerning this celestial body hardly any attention has been paid to refraction. The study of atmospheric refraction had, long since, made us acquainted with the laws of curved rays[2] but the first important attempt to investigate the influence which refraction in the Sun itself must have had on the course of the rays which reach our eye, and consequently on the optical image we get of it, was made by Dr. A. Schmidt. His paper "Die Strahlenbrechung auf der Sonne; ein geometrischer Beitrag zur Sonnenphysik"[3] leads to very remarkable results, and at any rate urges the necessity of submitting the existing theories of the Sun to a severe criticism from this point of view.

If it is taken for granted that refraction in the solar atmosphere must be taken into account we must also pay attention to those special cases in which extraordinary values—great or small—of the refractive index occur; in other words, the phenomenon of anomalous dispersion must be reckoned with.

[1] *Proceedings of the Royal Academy of Sciences*, Amsterdam.

[2] The literature on this subject may be found in a dissertation by O. Wiener, *Wied. Ann.*, 49, 105-149, 1893.

[3] Stuttgart, Verlag von J. B. Metzler, 1891.

It is my purpose to show that many peculiarities, which have been observed at the limb of the Sun and in the spots, may easily be considered as caused by anomalous dispersion.

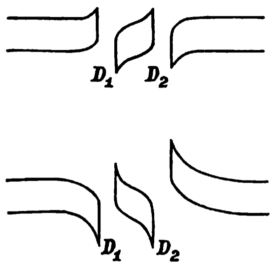
It is not difficult to obtain the experimental evidence that the index of refraction of sodium vapor for light differing but slightly in wave-length from that for the D lines, is very different from the index for the other rays of the spectrum.

H. Becquerel[1] used for the study of the phenomenon Kundt's method of crossed prisms, in a slightly modified manner. The image of the crater of an arc light was projected on a horizontal slit, placed in the focus of a collimator-lens. The parallel beam next passed through a sodium flame, which Becquerel had succeeded in giving the form of a prism with horizontal refracting edge, and was then, through a telescope lens, focused into an image of the horizontal slit, falling exactly on the vertical slit of a spectroscope of rather great dispersion. As long as the sodium flame was absent, a continuous spectrum was seen in the spectroscope, the height of which naturally depended on the width of the horizontal slit. When the flame was introduced in its proper place, and good care was taken to limit the parallel beam by means of an easily adjusted diaphragm, in such a manner that only such light could penetrate into the telescope lens as had passed a properly prismatical part of the flame, the spectrum clearly exhibited the anomalous dispersion. On either side of the two dark sodium lines the originally horizontal spectrum-band was boldly curved, so that for rays with wave-lengths slightly larger than λ_{D_1} or λ_{D_2}, the sodium vapor appeared to possess an index of refraction rapidly increasing in the neighborhood of an absorption line; whereas for rays of wave-lengths slightly smaller than λ_{D_1} or λ_{D_2}, the index of refraction rapidly decreased when approaching the absorption lines. The amount of the anomalous dispersion near D_2 exceeded that near D_1.

In repeating this experiment I obtained materially the same results. Moreover, I noticed a peculiarity in the phenomenon, not mentioned by Becquerel, and not exhibited in the diagrams

[1] *C. R.*, **127**, 399; and **128**, 145.

accompanying his paper. Becquerel states that when he introduced a flame, rich in sodium, the lines D_1 and D_2 appeared as broad, dark bands, and that on either side of both bands the spectrum was curved. According to his diagrams these displacements only refer to light outside the bands; the rays inside this region, in the more immediate neighborhood of the D lines, are totally wanting. Fig. 1 refers to a prismatic part of the flame, edge upwards; Fig. 2, to a prismatic part, edge downwards. Both cases represent the image as seen in a telescope, and are thus reversed.



FIGS. 1 AND 2.

I myself, however, have observed the phenomenon in the form of Fig. 3. The dotted lines indicate the places of D_1 and D_2. When the electric light is intercepted by means of a screen introduced between the flame and the horizontal slit, the D lines appear in those places as two faintly luminous, sharply defined slit-images. The light is faint because the flame is placed at a distance of more than 70 cm from the vertical slit, and its radiation is all but intercepted by the adjustable diaphragm, which allows only a beam of a cross-section of about 0.2 cm², to enter the telescope lens.

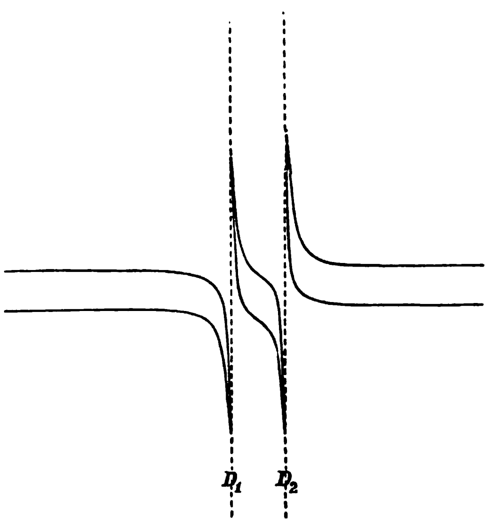


FIG. 3.

When next the arc light is allowed to cross the flame, the spectrum of Fig. 3 appears with such intensity that the bright sodium lines are undistinguishable in the center of the dark bands. In the upper and lower parts of the field of vision, however, they can yet be seen as continuations of the

four bright arrows of light which are, as it were, flashed forth from the horizontal spectrum into the dark.

By repeatedly intercepting and readmitting the light of the main source, I have actually convinced myself that the intense arrow-light, with the dispersion used, gradually passes into the faint light of the emission-lines, both with respect to intensity and place in the spectrum. A flat Rowland grating with 47,000 lines was used in the spectroscope; one spectrum of the first order being extremely brilliant. The crosswires of a micrometer eyepiece (65 divisions of which correspond to the distance of the D lines in the first diffraction spectrum) were repeatedly adjusted as close as possible to the extreme part that was yet distinctly visible of such an arrow, the sodium lines of the flame being all but invisible. I next removed the diaphragm near the flame, intercepted the main light so that the sodium lines now became clearly visible, and took a number of the readings of the emission line. The mean readings of two series of observations did not mutually differ by one division; the arrow, therefore, approached the D line to within 0.01 $\mu\mu$. From the data furnished by Becquerel[1] it can be inferred that the distance between the D lines and the most deflected parts of the arrows upon which, in his experiments, the crosswires could still be adjusted, was on an average greater than 0.1 $\mu\mu$.

I am not quite sure how this difference in the results must be accounted for; perhaps Becquerel's flame contained more sodium than mine; anyhow so much sodium is not wanted to produce strong anomalous dispersion.

The following experiment convinced me how narrow was in reality the absorption-region of each of the sodium lines. An additional lens of 20 cm focal distance was placed between the telescope lens and the vertical slit, in such a manner that on this slit was thrown the image of the prismatic part of the sodium flame, and not that of the horizontal slit, as before. In this image, therefore, all rays that had passed the flame and had been refracted in different directions, must be found reunited.

[1] *C. R.*, **128**, 146.

The absorption lines were now actually very narrow, the emission lines in some places all but covering them.

The additional lens being removed, the light-arrows forthwith reappeared above and below the rather broad dark bands in the curved spectrum.

It appears, therefore, from our observations that in spite of the considerable width of the dark bands in the main spectrum, the corresponding light is but very slightly absorbed by the sodium lines. The flame has allowed every kind of light to pass, even that of which the wave-length differed ever so little from that of the D lines; but it has caused these rays to be deflected from the straight line much more forcibly than the other parts of the spectrum lying further removed from the absorption lines.

Here, then, we have a case where the absorption spectrum of a vapor exhibits broad bands not deserving the name of absorption bands. The special manner in which the experiment was made enabled us to see what had become of the light that had disappeared around the sodium lines; but very likely the broad bands would have been attributed entirely to absorption if somehow this abnormally refracted light had fallen outside the field of vision of the spectroscope. In studying the absorption spectra of gases and vapors, we should be careful to see—which is not always done—that the absorbing layer shall have equal density in all its parts and shall not act anywhere as a prism. It would be worth while investigating in how far the anomalous dispersion can have influenced cases in which broadening or reversal of absorption lines have been observed.

In my arrangement the absorption lines were narrow, if the main light had passed through a nearly homogeneous and *non*-prismatic part of the flame.

The experiment, as described above, offers no opportunity for obtaining reliable values of the refractive indices. A better method to arrive at more reliable results is now being investigated; for the present all we can say is that the deviation of rays whose wave-length is very near λ_{D_1}, or λ_{D_2}, is at least

six or eight times greater than that which the remoter parts of the spectrum were subject to. Becquerel says that the index for waves greater than λD_1 and λD_2 may attain 1.0009; for waves on the other side of the absorption line the index falls considerably below unity. The line D_2 produces in a much higher degree than D_1 refractive indices smaller than unity;[1] the very high indices are represented in pretty much the same degree near D_1 and D_2.

From all this we infer:

1. Where light emitted by a source that yields a continuous spectrum traverses a space in which sodium vapor is unequally distributed, the rays in the neighborhood of the D lines will be much further deflected from their course than any others. Of all things this holds good of those rays whose wave-length differs so little from λD_1 and λD_2 that they can hardly be distinguished from sodium light. A pretty strong light, therefore, misleadingly resembling sodium light, but in reality owing its existence to other sources, may seem to proceed from a faintly luminous sodium vapor, in a direction deviating from that of the incident light.

2. A spectroscopic examination of the light that has traversed, in a fairly rectilinear direction, the space filled with sodium vapor, shows, in the places where the D lines are to be found, broad dark bands, owing to the fact that the light of these places in the spectrum has deviated sideways from its course and has not reached the slit of the spectroscope.

The former of these inferences we will now apply to certain phenomena in the neighborhood of the disk of the Sun; the latter to some peculiarities of the Sun-spots.

Let the arc *ZZ'* (Fig. 4) represent a part of the disk of the Sun, the observer being stationed far off in the direction of *O*. This *ZZ'* may be taken to be either the limit of the photosphere, or the critical sphere which, in A. Schmidt's theory of the Sun, plays such an important part. In either case, a ray emitted from

[1] In Fig. 3, page 187, the upper arrow near D_2 is defective and rather short compared with that near D_1.

any point *A* on the surface, at an angle of nearly 90°, will reach the point *O* along a path the curvature of which diminishes regularly, if we assume that the density of the Sun's atmosphere in a direction normal to the surface decreases continuously.

A ray emitted from *B* under the same circumstances will proceed along *BO'* and does not, therefore, reach *O;* the observer at *O* will see *A* lying just within the margin of the disk of the Sun; light proceeding from *B* is invisible to his eye. Slight irregularities of density in the atmosphere on the path *AO* will

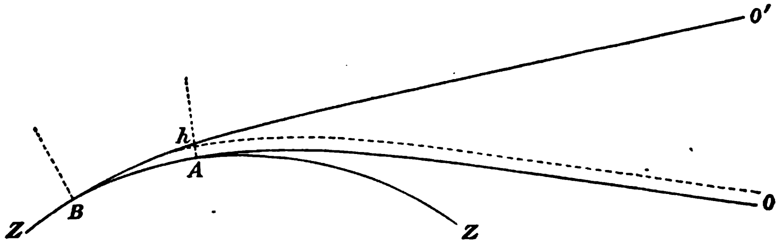


FIG. 4.

indeed deflect the course of the rays, but only slightly if the gases have a normal index of refraction. The irregularities show themselves as shallow elevations and depressions in the edge of the Sun's disk. In the same manner, rays like *BO'* do not materially deviate from the course which they would have to follow in a perfectly calm atmosphere of continuously decreasing density.

Let us now suppose unequally distributed sodium vapor to be present near *A* above the limit *ZZ'* (the photosphere). We suppose this vapor to be hardly luminous, if at all. The greater part of the beam of white light *BO'* is only slightly irregularly refracted in it, just as in the other gases to be found there; but those rays whose wave-length differs but slightly from λ_{D_1} or λ_{D_2} are much more deflected, and they may even follow the course indicated by the dotted line *BhO*. Then from *O*, at a small distance *Ah* above *A*, light may be seen proceeding from *B*—a source of light with a continuous spectrum—closely resembling sodium light. A spectroscopic examination of this

light, however, will show that it differs more or less from that of the D lines.

It might be thought that only rays with an abnormally high refractive index, *i. e.*, with wave-lengths rather greater than λ_{D_1} or λ_{D_2}, can reach the observer along the path *BhO*. Such, however, is not the case; for if above *A* there were a layer comparable to a prism with the refracting edge perpendicular to the plane of the cut and with base turned upwards, rays with an index smaller than unity must be able to traverse the path *BhO*.

Accordingly in the spectrum of the light that appears outside the Sun's disk we can expect to find rays which are situated on either side of the D lines; perhaps the probability is a little greater for the light on the red side of the absorption lines, because from *A* to *h* the density is more likely to decrease than otherwise.

It is further clear that very near the limb there is the greatest probability of also seeing light that differs relatively much in wave-length from the sodium light; for there a less degree of abnormality of index suffices to deflect rays in the direction of *O*. On the other hand, far above *A*, we can, as a rule, discern only such light as is hardly to be distinguished from D light.

These actually prove to be the principal characteristics of the chromosphere lines. Generally they have a broad base and are arrow-headed. Compare the description and the diagrams to be found in Lockyer's *Chemistry of the Sun*, pp. 109 and 111.

Their typical form appears very strikingly in the hydrogen lines of the chromosphere.

There is no reason to assume that the above considerations, with regard to sodium vapor, do not hold good as well for other gases and vapors. With some of these the anomalous dispersion has been proved already;[1] with others we have been less successful, but the dispersion theories point to its existence in a greater or less degree in all substances.

The characteristic form of the chromosphere lines might, of course, also be accounted for, as is generally done, by the

[1] WINKELMANN, *Wied. Ann.*, 32, 439.

strongly radiating luminous gases and metallic vapors which are thought to be present in the chromosphere, and of which the density near the photosphere must then be taken to be very considerable and to be rapidly decreasing at greater distances. The observed light would then be emitted by those glowing vapors.

Our view of the origin of the chromosphere light does not by any means preclude the possibility of this light owing its existence, partly at least, to self-radiation of incandescent gas; what we have shown is that it may also be refracted photosphere light. Further investigation of the various phenomena of the Sun must decide which explanation goes farthest in considering the whole subject.

Sometimes the chromosphere lines appear under very singular forms, with broadenings, ramifications, plumes, detached parts, etc.[1] Thus far this has been accounted for only on the principle of Doppler, viz., by assuming that the radiating gases move towards, or away from us with tremendous velocity—even as much as 200 km per second and more. Astronomers are all agreed that this explanation is open to many objections, of which we need not remind the reader here.

Beside Doppler's principle, however, we find in the anomalous dispersion another, according to which a gas has the power to originate, under certain circumstances, light differing in wave-length from the characteristic rays of that substance.

Let us suppose, for example, that at some distance above the Sun's limb there is a quantity of hydrogen, with great varieties of density in some of its parts. It will emit not only its own characteristic light, but will, here and there, also deflect earthwards the photosphere light of adjacent wave-lengths. This will, of course, manifest itself in excrescences or ramifications of the hydrogen lines, or as isolated light patches in their neighborhood.

This phenomenon may be expected especially when the slit is adjusted for the examination of prominences where violent

[1] *Cf.* LOCKYER, *loc. cit.*, p. 120.

disturbances take place and where, consequently, considerable differences of density occur.

Though the present explanation of these irregularities in the spectrum is based, like the other one, on the hypothesis that violent disturbances in the solar atmosphere go hand in hand with them, yet the tremendous velocities, required when applying Doppler's principle, do by no means follow from it.

A portion, therefore, of all the light that reaches us from chromosphere and prominences *may* be due to self-luminosity of the gases to be found there; but another, and to all likelihood a very considerable portion is refracted photosphere light reaching us in a manner that reminds us of Töpler's well-known "Schlierenmethode." But there is this difference, that in the "Schlierenmethode" every kind of rays emitted by the source helps to bring out the same irregularities of the medium by ordinary refraction; as a rule no color-phenomena are to be seen, the dispersion of most media being small compared with the average deviation of rays. The chromosphere gases, on the other hand, are to be seen in characteristic colors, because they have an exceptionally high or low refractive index for particular sorts of light. In this case the dispersion is great in comparison with the average deviation of the rays.

Momentarily disregarding the self-radiation of the gases in the solar atmosphere we shall—if the slit is radially adjusted—find those chromosphere lines to be longest and brightest which show the greatest anomalous dispersion. We have seen that the two sodium lines show considerable difference in their respective powers to call forth this phenomenon. Let us make the pretty safe supposition that also the different hydrogen lines and the other chromosphere lines show analogous individual differences and we have the explanation why in the chromosphere spectrum some lines of an element are long and others short, and why the relative intensity of the lines of an element is so different in this spectrum from that in the emission spectrum or in the Fraunhofer absorption spectrum. A careful examination of the anomalous dispersion of a great number of substances will, of

course, have to be made before it can be made out in how far our view will account for the facts already known or yet to be revealed in the chromosphere spectrum. Amongst other things it must then appear whether those elements whose lines are most conspicuous in the chromosphere light do actually cause uncommonly great anomalous dispersion—a wide field for experimental research, the exploration of which has only just commenced.

On the other hand, as regards the self-luminosity of gases, Lockyer's ingenious experimental method of long and short lines affords us an invaluable help to investigate what is the influence of the temperature (and the density ?) of the radiating substance on the emission spectrum. So it seems possible to make out by experiment whether it is radiation or refraction to which the different chromosphere lines are most probably due.

This decision ought, of course, to be founded on a most accurate knowledge of the character which each of the spectral lines of the solar atmosphere exhibits in different circumstances. The coming total solar eclipses offer a good opportunity to observe the chromosphere spectrum minutely, little disturbed by the dazzling light of the photosphere. Especially it is to be hoped that some good spectrograms will be obtained with high dispersion apparatus.

Let us now consider from the point of view of anomalous dispersion the well-known "reversing-layer" which in total eclipses causes the so-called "flash." We have seen before that the theory of dispersion assigns anomalous dispersion to all waves whose periods lie near each characteristic vibration-period of a substance; but the amount of the anomalous dispersion may be slight. In such a case the arrows, in an experiment similar to that described for sodium-light, would be short and narrow, but, for all that, of great intensity. If, therefore, such substances exist in the solar atmosphere even at great distances from the photosphere, with irregularities in density similar to those assumed for sodium, hydrogen, etc., the anomalous refraction will betray the presence of those substances merely in the

immediate vicinity of the edge of the Sun's disk, and only during a few seconds at the beginning and the end of the totality of an eclipse.

This view of the subject makes it a matter of course that the lines of the flash should be very bright; for properly speaking it is not chiefly the radiation emitted by the vapors that we observe, but photosphere light of pretty much the same wave-length. Nor is it necessary that the gases in those places should be of extraordinarily great density, or that their presence should be restricted to a thin reversing layer — one of the most mysterious things the solar theory has led up to and one which astronomers have tried to escape in various ways.

The light of the chromosphere and of the flash lines may be symmetrically distributed on either side of the corresponding Fraunhofer lines; if so, they seem to coincide with the latter; but in certain places of the limb the case must arise that the bright lines would appear to have shifted their position with regard to the absorption lines. For in proportion to the distribution of the density of the vapors, it will be, in turn, especially the rays with very great refractive index (on the red side of the absorption lines) and those with very small refractive index (on the violet side of them) that are curved towards us.

As, upon the whole, the density of the gases of the solar atmosphere will decrease rather than otherwise in proportion as they are farther from the center, it may be expected (according to what we observed with regard to Fig. 4) that the bright lines will oftener shift their position with respect to the Fraunhofer lines in the direction of greater wave-lengths than in that of smaller.

These details will probably become clearly visible in the eclipse-photograms obtained with slit-spectrographs with great dispersion. It is not impossible that in many of the chromosphere lines a dark core may be seen.

Summarizing what we have said, we maintain the following position with respect to that part of the solar atmosphere situated outside what is called the photosphere.

The various elements whose presence in that atmosphere has been inferred from spectral observations are much more largely diffused in it than has generally been assumed from the shape of the light phenomena; they may be present everywhere, up to great distances outside the photosphere, and yet be visible in a few places only; their self-radiation contributes relatively little to their visibility (with the possible exceptions of helium and coronium); the distances, at which the characteristic light of those substances is thought to be seen beyond the Sun's limb are mainly determined by their local differences of density and their power to call forth anomalous dispersion.

In conclusion I wish to say a few words concerning phenomena presented by the Sun-spots. In the spectrum of these spots many of the Fraunhofer lines appear considerably broadened (see, *e. g.*, the diagram in Lockyer, *Chemistry of the Sun*, p. 100). The cause for this has been sought in the presence of very dense absorbing gases, and the broad bands have been attributed exclusively to absorption. The question is whether the second conclusion that we have drawn from the phenomena of refraction in a sodium-flame (p. 190) is not applicable here.

We proceed from the opinion that in a Sun-spot are found great differences of density dependent on strong vertical currents or, according to Faye, on vortex movements in the atmosphere. The phenomenon is commonly localized in the level of the photosphere, at all events, not far above or below it. Now if the entire body situated within the photosphere actually forms a sharp contrast with the outer atmosphere, and if its surface radiates to every side an almost equally intense light with a continuous spectrum, the broadening of the Fraunhofer lines and the darkness of the spots cannot be accounted for by merely attributing the spots to differences of density. The phenomenon must then be set down to differences of temperature, smaller radiating power, condensation, stronger absorption, etc.

Matters are different, however, if A. Schmidt's view is taken to be the correct one, according to which the Sun's limb is an

optical illusion caused by regular refraction in a gradually dispersing, nowhere sharply bounded, mass of gas. In this theory the apparent surface of the photosphere is merely a critical sphere, characterized by its radius being equal to the radius of curvature of rays of light traveling along its surface horizontally; there is not the least question of any discontinuity in the distribution of matter on either side of this spherical surface; inside as well as outside the critical sphere the average density of matter and its radiating power increase gradually towards the center, and it is only at great depths that the condition of matter need be such as to emit a continuous spectrum.

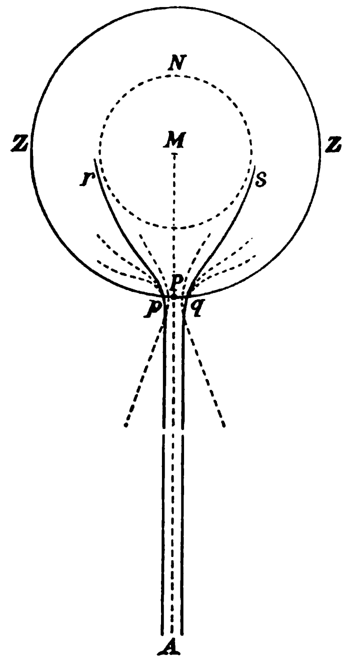


FIG. 5.

Let the circle ZZ' in the diagram (Fig. 5) be the section of the critical sphere with the ecliptic, and let the Earth be in the direction MA. Suppose a spot visible in the center of the Sun's disk; it is seen projected on the critical sphere in P. Now let us suppose that the density increases all around from the center P of the spot, locally producing there cylindrical, rather coaxial, layers with the line of vision for basis. Rays pA and qA suffering normal refraction, may, as is easily seen, have traversed in the Sun the paths rp, sq, and may, therefore, originate, not, it is true, from the most luminous center, but yet from pretty intensely radiating parts of the Sun. They yield the white light of the umbra and of the penumbra, which, though standing out dark against the other parts of the Sun, yet are relatively bright enough.

Slight irregularities in the distribution of density around P render it possible that parallel to PA there emerge rays that have

followed other paths which, nevertheless, will essentially be included in the solid angle *rPs*.

But rays which have undergone anomalous dispersion and yet reach our eye in a direction parallel to *PA*, must have proceeded from a much greater diversity of directions, and need not, therefore, have been emitted in such numbers by the intensely luminous central part of the Sun.

We may also put the matter thus: Of all the light, coming from the intensely radiating nucleus of the Sun (to which may be reckoned all that lies within the sphere *N*) and emerging from the vicinity of *P*, those rays, whose refractive index is abnormally high or low will be more effectually dispersed in all directions, owing to the local differences of density, than rays with a normal index.

The consequence is that the observer, looking in a given direction towards *P*, will see less of those abnormally refracted rays than of the other light. Those rays will, therefore, seem absent in the spectrum of the spot: the Fraunhofer line is seen broadened.

Whereas our considerations concerning the chromosphere light were made independently of any theory of the nature of the photosphere, the present broadly outlined explanation of the phenomenon of the Sun-spots is to a certain extent based on the theory of Schmidt — with which, in fact, it stands or falls.

If subsequent investigations should prove the lines that generally appear broadened in the spectra of the spots, and those which call forth strong anomalous dispersion, to be identical, this would support Schmidt's solar theory.

For the rest it is easy to see that henceforth the principle of anomalous refraction will have to be considered side by side with that of Doppler in every instance when an explanation is required of the many irregularities that have been observed in certain Fraunhofer lines, both near the Sun's limb and in faculae and spots; *cf.* the illustrations in Lockyer's *Chemistry of the Sun* pp. 122 and 123; Young, *The Sun*, pp. 157 and 210; Scheiner, *Die Spectralanalyse der Gestirne*, p. 349.

Such phenomena *may* be caused by refraction, whereas hitherto the only possible explanation was sought in the assumption of tremendous velocities in the line of vision.

The foregoing considerations may suffice to show that anomalous dispersion naturally accounts for a great number of solar phenomena. At any rate no future theory of the Sun can ignore the laws of refraction.

NOTE ON INQUIRIES AS TO THE ESCAPE OF GASES FROM ATMOSPHERES.[1]

By G. JOHNSTONE STONEY.

WE have now three investigations which profess to supply information about the escape of gases from atmospheres. Two of them, those of Messrs. Cook and Bryan, reason forward by the help of the kinetic theory of gas from the supposed causes; the third, which is that preferred by the present writer, reasons backward by the help of the same theory from the observed effects.

Mr. Cook's investigation, which will be found in the ASTROPHYSICAL JOURNAL for January 1900, seeks to compute the proportion of molecules which can attain the speed requisite for escape by means of the formula which Maxwell published in 1860, assigning the proportion of particles whose speed lies between v and $v + dv$, in a system of colliding particles intended to represent an isotropic portion of gas.

Professor Bryan's investigation[2] is based on the investigations made since 1866 into the way in which energy tends ultimately to be partitioned among the various motions possible within a self-contained dynamical system of bodies. The system need not be isotropic, since the bodies may be moving in a constant field of force.

An inquiry by the present writer into Mr. Cook's method of dealing with the problem is attempted in the May and June numbers of the ASTROPHYSICAL JOURNAL for 1900, and in the present paper a similar attempt is made with reference to Professor Bryan's.

Both Mr. Cook and Professor Bryan predict the proportion of molecules which can escape from an atmosphere by deducing the proportion from its supposed causes, and in this respect are in contrast with an investigation previously published, which

[1] Read before the Royal Society on June 21, 1900.

[2] *Proc. Roy. Soc.*, April 5, 1900, p. 335.

sought to ascertain from the observed effects of escape where and on what scale it has in fact taken place.[1]

Where, as in the present instance, the *a priori* and *a posteriori* methods have led to inconsistent numerical results, there must be a mistake or mistakes somewhere, and it is incumbent upon us to search till these are detected. If they can be found and corrected an important advantage will be gained. Professor Bryan, at the end of his letter in *Nature* of June 7, 1900, indicated one place where a mistake may have been made, viz., in the assumed relation between temperature and the kinetic energy of the translational motions. Another mistake may perhaps have been made in assuming the legitimacy of treating the partition of energy when molecules move in a field of force, as though the only partition to be considered is between these molecules, whereas no field of force can exist unless it has been produced by some physical agent, upon which every motion that goes on within the field must react. In consequence of these reactions no field of force in which any motion occurs can be accurately constant, and a partition of energy based upon the supposition of its constancy is a theorem in rational dynamics, but has no counterpart in nature.

Thus, in the case of the Earth's atmosphere, the anisotropic condition of its outer layers is due to the field of force which exists in the neighborhood of the Earth; and when we are obliged to take into account this anisotropic condition, *as we must when dealing with the escape of gases from atmospheres*, this is to be done (when we are treating the problem as one of partition of energy) by including as molecules between which the partition has to take effect not only the gaseous molecules, but also all the other attracting molecules which provide the field of force.

[So again with reference to the never-ceasing turmoil which goes on in the atmosphere, which near the surface of the Earth exhibits itself in tempests, thunderstorms, and other phases of weather, and which in the upper regions includes phenomena

[1] See memoir by the present writer in the *Scientific Transactions of the Royal Dublin Society*, 6, Part 13, or in this JOURNAL, January 1898. And for further evidence that helium is escaping from the Earth see *Nature* of May 24, 1900, p. 78.

still more extensive and swift. It is manifest that these events increase the opportunities which gaseous molecules have of escaping from the Earth, and that accordingly *they must be taken into account*, either explicitly or implicitly, in every valid inquiry as to the rate of escape.

To take them into account in an investigation based on the partition of energy, we have to extend that partition to whatever agency produces the turmoil. Now the activity within the atmosphere (and in fact almost every molar activity upon the Earth other than the little which is attributable to tidal action or to such minor agencies as earthquakes and volcanoes) is caused by the shiftings about of energy which comes in between the continuous advent of energy by radiation from the Sun, and its continuous escape from the Earth by radiation into space. Hence, to render an investigation by the Boltzmann-Maxwell law valid, it is necessary to extend the partition of energy beyond the atmosphere—first to the solid Earth, so as thereby to take account of the anisotropic character of some of the atmospheric strata (which facilitates the escape of gas); and secondly to embrace at least the Sun and the ether between the Earth and Sun, so as thereby to take into account the turmoil in the upper regions of the atmosphere (which further increases the rate of escape). It seems to be only when these extensions shall have been effected that a generalized law such as the Boltzmann-Maxwell law for the partition of energy between the various degrees of freedom can become competent to furnish any information with reference to the rate at which gaseous molecules actually do escape from the Earth.—July 17, 1900.]

Then as regards temperature. The temperature of a solid is in reality twofold: it is either its radiation temperature or its conduction temperature. These are physically distinct, although in all but some exceptional cases they are so nearly proportional to one another that they may be given the same mathematical expression. So, again, when dealing with gases we do well to keep in mind the essential distinction between radiation temperature and what may be called convection temperature. The

temperature of an isolated gaseous molecule moving by itself through space is of the first kind only, and depends exclusively on the energy of the internal motions—those motions within the molecule which enable it to absorb or emit radiant heat—and *it is in no degree affected by the kinetic energy* of the translational motion of the molecule; whereas if the same molecule form part of a gas, it meets with encounters with other molecules or with the walls of a containing vessel, and at each such encounter there is a partition of energy between the translational and the internal motions, and in consequence of this the kinetic energy of the translational motion becomes a part of what determines that average power of absorbing and emitting radiant heat which (when estimated over a time embracing a sufficient number of encounters) is the proper definition of the radiation temperature of the molecule. Accordingly the average kinetic energy of the translational motions of the molecule enters into its mathematical expression. If the gas be dense, encounters are frequent, and Δt, the time requisite for the averages, may be brief. In this case the radiation temperature of a molecule, while the gas is undergoing some change in its condition, is predominantly the outcome of its encounters, and depends mainly on the molecules that surround it; whereas if the gas be very much attenuated, then the radiation temperature of the molecule during a period of transition will depend mainly on what influences then reach it from the surrounding ether, and will be but in a subordinate degree affected by the encounters to which the molecule at about that time happens to be subjected.

This is a matter which needs to be very fully taken into account when we attempt to estimate the escape of molecules from the Earth's atmosphere, inasmuch as a large part of the heat radiated by the Sun to the Earth is absorbed by the gaseous molecules which happen at the time to be moving about in those strata of the atmosphere from which alone there can be any effective escape. Accordingly it will need to be carefully scrutinized whether this has been either explicitly or implicitly taken into account in the attempts which have been made to determine *a priori* the rate of escape.

When the molecules of a gas or of a mixture of gases move in a field of force such as that surrounding the Earth, convection currents can exist, and the term temperature as applied to the gas becomes ambiguous. It may have either of two distinct meanings, one of which has reference to the transport of heat by convection and by the consequent sweeping of successive portions of gas against bodies immersed in it, and the other has reference to the exchanges of heat by radiation with those or with more distant bodies. These are different physical events, and the assumption that they stand in a fixed ratio to one another is convenient, but is often not true. It is probably legitimate to regard it as approximately holding good in a gas which has nearly reached a final, *i. e.*, an unchanging condition, and where the problem with which we are dealing does not need our making any closer scrutiny than as to what, on the average, happens to a sufficiently large swarm of molecules within a sufficiently long duration; but it is not true while gas is passing through transition stages, nor is it true of individual molecular events, or of small swarms of events, even in gas which has reached its final state.

Now, none of the gases of the atmosphere have even approached any such state. Changes incessantly go on in the open air at the bottom of the atmosphere, and the extent and abruptness of the changes that as incessantly go on in its upper regions are probably greater.

Again, the consequences of cumulative effects arising in the illimitable trains and combinations of encounters that are taking place, and of associated events in the ether, will also need to be either explicitly or implicitly taken into account in any valid investigation of the escape of gases from atmospheres by the deductive method.

All the circumstances that have been referred to would have to appear among the data of an ordinary dynamical investigation of the escape of an individual molecule from an atmosphere, if such an investigation were possible; and the claim of a generalized theorem like that of the partition of energy to

render it unnecessary to go into these details, ought to be carefully scrutinized. In one case at least the claim does not appear to stand this test, viz., in reference to the supposed legitimacy of the assumption that the field of force surrounding the Earth is constant. Though its variations are minute they are none the less real and are due to interactions between each gaseous molecule and all the molecules of the solid Earth, as real as are the interactions between gaseous molecules when they encounter, and as much entitled to be taken into account, when we seek to carry on the investigation in the region of generalized propositions. It should be kept in mind that in reference to what happens within this region, the plea of being so minute as to be of negligible amount is not admissible. Whether a very small factor may or may not be neglected must be determined independently in each individual case; and in the above instance the decision is that it may not be neglected.

Other corrections might be suggested along with the principal ones noticed above — that relating to the two kinds of temperature, that relating to the field of force, and that relating to turmoil in the atmosphere; but what seems most to be wanted is that we should recognize that any law for a distribution of energy within the atmosphere by itself, can only come approximately into practical effect after the lapse of a sufficient duration, and throughout a column of the atmosphere from which accidents are excluded; and that this law will not be the Boltzmann-Maxwell law, which may not be so restricted.

Thus, let us imagine a cylinder like a great Tower of Babel, reaching to the top of the atmosphere, with walls competent to intercept dynamical, electrical, and all other extraneous influences other than gravitation. The air within this tube would consist of molecules, moving in a field of force caused mainly by the Earth's attraction and rotation, and this column of air might perhaps after some such period as a month, a year, a century, or a thousand years nearly attain such a distribution of energy as that indicated by some law. But if, while this process is maturing, a wind overthrows the tower, sweeping away the air it contained

and substituting other air under new conditions, and subject to all the chances of uprushes, downrushes, thunderstorms, auroras, cyclones, cloud, sunshine, rain, etc.; then after all or any of these or of the like accidents, the tower would have to be rebuilt before any portion of the atmosphere extending from the bottom to the top could find itself in a position even to commence the first steps of an advance towards at some future time complying with the law.

The supposition then that the Boltzmann-Maxwell law can be restricted within our existing atmosphere would appear to be a mistake; and if so the inferences from that law are not part of a real interpretation of nature. It need not, therefore, be matter of surprise that, in the case of helium, the facts of nature seem to negative those inferences.

The weather which will prevail over the Earth this day month will be the outcome of the present molecular state of the Earth, and of the molecular events which will happen in the meantime; but our power of stating in mathematical form the existing state of the Earth, and our knowledge of molecular physics, are not such as would enable us to predict that future weather by the *a priori* or deductive method of proof. The difficulties in this case are easily seen; and they are instructive, since the escape of gas from the Earth depends on phenomena which are probably as complex as those which determine the weather and as little amenable to treatment by the deductive method.

Any such distribution of energy as that assigned by the Boltzmann-Maxwell law would, if it could be realized, be brought into existence by the gradual effacement of excesses which had previously existed; from which it would appear to follow that excesses prevail in our existing atmosphere greater and more numerous than could exist in an ideal atmosphere that obeyed that law. It is probable, therefore, that in our actual atmosphere there are more opportunities for the escape of molecules than there would be in the ideal atmosphere — a conclusion which accords well with the fact that the actual rate of escape exceeds those computed by Professor Bryan and Mr. Cook.[1]

[1] See *Nature* of May 24, 1900, p. 78, second column.

THE COMPLETE EMISSION FUNCTION.

By P. G. NUTTING.

THE Wien[1]-Paschen[2] formula representing the emission of perfectly radiating bodies in its relation to their temperature and the period of the emitted radiation has been quite thoroughly tested in the region of the continuous spectra. Wanner[3] has shown the possibility of its holding, in the case of an enclosed source, even in the sodium line-spectrum. But to represent the free emission of imperfect radiators, in whose emission spectra there are maxima independent of the temperature at particular wave periods, the formula is quite inapplicable. If, for instance, we attempt to calculate the temperature of the Sun, using the above mentioned formula and the amount of radiation of a given wave period received at the Earth, we arrive at the absurd result, as Planck has shown,[4] of a different solar temperature corresponding to the emission of each wave period used in the calculation. It has seemed worth while to construct an emission function of wave period and temperature which should hold for the free emission of all substances at all temperatures, as well in the line as in the continuous spectrum. The theorems and methods of the modern theory of functions will be used in its construction.

So many terms are in use relative to emission and emitting power, that we may avoid confusion in what follows by specifically stating the meaning of the terms employed. In all cases the temperature of the emitting body is supposed maintained, no law of cooling being concerned. Unlike *surface conductivity*,[5] these terms take no account of convection, conduction, or of

[1] W. WIEN, *Wied. Ann.*, **58**, 662, 1896.

[2] F. PASCHEN, *Wied. Ann.*, **58**, 491, 1896.

[3] H. WANNER, *Wied. Ann.*, **68**, 143, 1899.

[4] M. PLANCK, *Ann. d. Ph.*, **1**, 722, 1900.

[5] T. PRESTON, *Theory of Heat*, London, 1894, p. 443.

radiation received from surrounding objects; thus assuming emission in a vacuum with non-reflecting surrounding objects at the absolute zero of temperature. If the emission be found to be a varying function of the pressure, or of the density of the emitting body, then these are supposed constant, or else the emission corrected for their variations. Each of the five quantities defined applies as well to the total integral emission of waves of all periods as to the particular emission of waves of one period. The former is the integral of the latter from zero to infinity with respect to the period in all cases. The defining equation of each quantity defined may be easily written.

The *emission* from a body is the energy leaving its whole surface by radiation in a unit of time. It is the integral of the specific emission over the surface. We may consider either the *total* emission of all wave periods or the *particular* emission of a single wave period.

The *specific emission* of a body is its emission per unit area of surface. It is the energy leaving each square centimeter of its surface by radiation, in each second, in all directions. This appears to have been the unit used by Paschen.

The *intensity of emission* is the specific emission from a body perpendicular to its surface, the energy radiated normally from each square centimeter of the surface of a body in each second. Consider an imaginary tube whose walls are normal to the radiating surface, and which cut unit area from it. Then the intensity of emission is measured by the energy traversing any cross-section of the tube in a second, only that radiation being considered which never crosses the walls of the tube. Cotton, in his discussion of Kirchhoff's law,[1] apparently assuming Lambert's law, defines intensity of emission as measured by the total energy contained at any one time within an imaginary cylindrical tube of unit section, cutting the emitting surface at any angle.

The *emission constant* for any given temperature and for any particular wave period or group of wave periods, is the intensity

[1] A. COTTON, *Rev. Gen. des Sciences*, February 15, 1895. Also this JOURNAL, 9, 250, 1899.

of emission from a black or perfect radiator. Where observed data are lacking or conflicting, the validity of the Wien-Paschen formula is assumed, together with the values of the constants determined by Paschen.

The *emitting power* of a substance is the ratio of its intensity of emission to that from a perfect radiator at the same temperature and under the same conditions. Like reflecting and absorbing power as commonly defined, its value lies between zero and unity for all substances in all conditions. It is perhaps more easily determined experimentally than any of the other quantities above defined, but intensity of emission is the simpler function mathematically and will be used in this discussion.

The intensity of emission being a function of the entirely independent arguments temperature and wave period, we may construct each function separately and then combine them in any manner such that each argument shall enter the function of the other as a parameter without affecting its form.

Consider first the intensity of emission as a function of the temperature. So far as we know from experimental evidence, the function is holomorphic over the whole region, for all substances in all conditions, and for all wave periods. It is continuous and single-valued in both argument and function throughout. Having no roots other than zero, it cannot be an integral, algebraic polynomial. Having no poles, it cannot be a fractional, algebraic function. It is obviously not polygenic, elliptic, nor automorphic. It cannot be a circular function, for it is not periodic, nor has it finite zeros. The remaining exponential function does satisfy the conditions. We reject the direct exponential ae^{bT} as giving a finite value at zero. We have, then, the inverse exponential function

$$E = ae^{-b/T}, \qquad (1)$$

satisfying all the above conditions. We reject the more general form, in which the second member is a sum of similar terms, as being unnecessarily complicated for expressing all the conditions at present known.

Either a or b, or both, may contain functions of the wave period. In the complete function, they may be found to contain, also, some function of the temperature which makes the emission decrease very rapidly above the temperature of vaporization, but we have yet no experimental evidence that it is necessary to impose such a condition. The condition cannot be imposed without making the function very much more complicated in form. If the intensity of emission, corrected for differences in volume or pressure, be found to decrease rapidly at temperatures above the temperature of vaporization only for waves of a certain period, the fact will be taken account of by a period parameter, and not a temperature parameter, in the coefficient a.

The intensity of emission as a function of the wave period is continuous and is single-valued in the argument for all substances, with all surface conditions, at all temperatures. It has the value zero at zero and infinity, and only at these points. For a perfect radiator it has a single maximum which varies with the temperature. As with the emission-temperature function, we are again limited to the inverse exponential, but with the factor τ^{-n}, where τ is the period of vibration, this will make the function vanish for very long waves.

For a perfect radiator we have then

$$E = \alpha\tau^{-n} e^{-\frac{\beta}{\tau}}, \tag{2}$$

satisfying the general conditions imposed. Combining the second function with the first, we have the familiar

$$E = A\tau^{-n} e^{-B/\tau T}, \tag{3}$$

holding for all substances having but a single maximum, and that varying with the temperature. Its maximum value

$$E_m = A\,(n/Be)^n\, T^n \tag{4}$$

corresponds to a period $\tau_{max} = B/nT$. The total intensity of emission at any temperature, which is the integral of (3) with respect to the wave period, is easily obtained[1] by integrating it as an

[1] This integration is given by PASCHEN, *Wied. Ann.*, **60**, 666, 1897.

Eulerian integral of the second kind. The total intensity of emission is thus

$$E_0 = AB^{1-n}\Gamma(n-1)\,T^{n-1}\,, \tag{5}$$

where $\Gamma\ (n-1)$ denotes the ordinary gamma function.

For the particular value $n = 5$, formula (3) is similar to Wien's, and (5) expresses Stefan's law.

Evidently equation (3) cannot represent the free emission from an imperfect radiator, in whose isothermal emission curves there are maxima not varying in position with the temperature.

The emission from rock salt, for instance, is very largely confined[1] to the region in the immediate vicinity of 50μ. In order to represent the emission from such a substance, we must interpose in (3) a sharp maximum or a pole. This is most simply done by writing

$$E = A\,(\tau - \tau_m)^{-n}\,e^{-B/\tau T}\,. \tag{6}$$

This satisfies all the conditions imposed on (3) except that it is meromorphic, having the constant polar maximum, τ_m. We cannot put the polarity in the exponential in any simple form without violating the conditions imposed. But E must be always real and positive, and this condition limits n in (6) to even whole numbers. That n may be restricted only to real positive values, we may write instead of (6),

$$E = A\tau^{-n}\,(\tau - \tau_m)^{-2}\,e^{-B/\tau T}\,. \tag{7}$$

Formula (7) should hold for any substance having but a single maximum of constant period. But most substances have more than one such emission maximum (spectrum line). For substances having m such maxima, (7) is generalized by writing

$$E = A\tau^{-n}\,e^{-B/\tau T}\,\Sigma_{m=1}^{m}\,(\tau - \tau_m)^{-2}\,, \tag{8}$$

holding in general for the free emission of all substances. In its still more general form, each polar fraction, $(\tau - \tau_m)^{-2}$, might have a different coefficient, but we have not sufficient data at present to determine whether or not this generalization is necessary. We may note in passing that these polar maxima $\tau_1 - - - \tau_m$, of the emission-period function, are identical with

[1] E. ASCHKINASS, *Ann. d. Physik*, **1**, 60, 1900.

the poles of the reflection-period and absorption-period functions, and that the poles of the refraction-period function are included among them.

If the polar maxima τ_m were absolute constants, (8) would give the emission an infinite and therefore too large value for $\tau = \tau_m$. But the finite width of the spectrum lines shows that we must regard τ_m (which may perhaps be identified with molecular or atomic period) as varying rapidly and continuously within certain very narrow limits. Suppose we replace τ_m by $\tau_m + a \cos k$, where a is an absolute constant and the time derivative of k is very large. Then the polar maximum has all values from $\tau_m + a$ to $\tau_m - a$ in rapid succession, so that if the observation of the emission extend over any considerable interval of time, it will not appear large. Even a very small value of a brings the emission maximum down to a moderate value. When a is large, the emission maximum is low and broad. In a very general way a appears to be proportional to τ_m, that is, for a given substance having a number of spectrum lines, those lines of greatest period are often the widest. And the gases of small molecular weight often have narrower and more sharply defined maxima even in the infra-red than substances of greater molecular weight.

Formula (8) agrees very well with the scant data at present available. It gives a curve closely resembling those obtained by Rosenthal[1] and by Rubens and Aschkinass.[2] For periods much greater than τ_m and in general for low temperatures, the effect of the presence of the polar constant is vanishingly small and (8) reduces to (3). Nearer τ_m and within a few octaves of it, the emission given by formula (8) is much less than that given by (3), using the same constants. The defect in the Wien-Paschen formula in this region was noted by Rosenthal. On the side of the shorter waves, the polar period τ_m reduces the emission much more rapidly to a much smaller value than would be given by the formula lacking it. At a distance of a few octaves from

[1] ROSENTHAL, *Wied. Ann.*, **68**, 783, 1899.

[2] RUBENS and ASCHKINASS, *Wied. Ann.*, **64**, 589, 1898.

any τ_m on the side of the shorter waves, the whole coefficient of the exponential becomes practically a constant and the emission is very slight.

In other words, by formula (8) the emission of any body at a distance of a few octaves from its constant maximum of greatest period, on the side of the greater periods, is very like that from a black body. It differs from that from a perfect radiator chiefly on account of its surface condition. But on the side of the shorter periods from even the first polar maximum, the emission is entirely different from that from a black body and in that region formula (3) cannot hold for any temperature or any wave periods. Between the spectrum lines and within any considerable distance of any line the emission is very slight, in fact of lower order and practically zero. The total radiation in this region is thus nearly all confined to the lines themselves, at any temperature.

These deductions from formula (8) agree well with known facts. Most metals give for relatively low temperatures and great periods an emission very similar to that from a perfect radiator. Paschen found that even bright platinum radiated sensibly as a black body. But in the region of the line-spectra of the metals, for relatively high temperatures and short periods, the emission is of quite a different character and practically confined to the emission maxima. Formula (8) covers both cases equally well. Even glass and the colorless crystalline salts having emission maxima far in the infra red, emit and absorb very slightly on the shorter period side of these maxima.

BERKELEY, CAL.
May 1900.

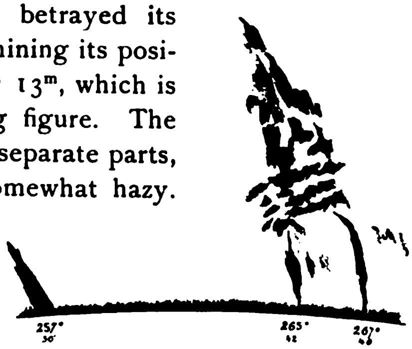
RISE OF A LARGE PROMINENCE ON JUNE 1, 1900.

By J. FÉNYI, S.J.

AFTER a long period of comparative quiet in the solar atmosphere I now have to report a phenomenon of extraordinary violence which appears to signalize a stormy awakening of renewed activity.

At 2^h Gr. M. T. on June 1, I observed at the Haynald Observatory in Kalocsa a prominence which rose with a rapidity seen only in case of the most violent eruptions, and reached the altitude 431″, which is extremely high for the present epoch of minimum. The special significance of this altitude appears from the fact that the highest prominences of the years 1896, 1897, and 1899 attained only the heights, respectively, of 196″, 197″, and 149″.

In the usual observation of the Sun's limb I found in position-angle 265° 42′ to 267° 40′ a prominence of moderate height whose intense brilliance betrayed its eruptive character. After determining its position, a drawing was made at 2^h 13^m, which is reproduced in the accompanying figure. The prominence consisted of several separate parts, which were very bright and somewhat hazy. The measurement of the height with the filar micrometer was difficult, yielding a very uncertain value of 93″. In order to determine the height with certainty, and to follow the rise of the prominence, I now let it run across the slit, noting also the transit of its lower part, as the two flames which formed the base were already dissolving and disappeared during the transits; so that at the last transit nothing at all was visible up to a height of 188″, or 136,000 km, while the separated parts preserved their forms up to 431″. The results of



the measures are collected in the following table. The first column contains the exact time of the measurement of the vertex; the second gives the height of the prominence calculated from the transits; the third gives the duration of each transit, while the fourth contains the mean velocity, in kilometers per second, of the ascent in the following interval, 1″ being taken as equal to 725 km.

RISE OF PROMINENCE ON JUNE 1, 1900.

Gr. M. T.	Height of vertex	Duration of transit	Velocity	Gr. M. T.	Height of base
$2^h\ 14^m\ 8^s.3$	289″.85	$21^s.5$	546 km	$13^m\ 57^s.2$	144″.56
14 41 .5	323.87	23 .3	231	14 29 .6	158.46
15 16 .4	334.99	24 .1	371	15 3 .0	148.73
15 51 .7	353.06	25 .4	187	15 37 .3	152.90
16 29 .0	362.72	26 .1	471	16 15 .8	190.43
17 16 .2	393.37	28 .3	423	17 1 .4	187.65
18 3 .8	421.17	30 .3	138	17 47 .2	190.43
18 55 .0	430.90	31 .0		18 37 .5	187.65

The fifth column gives the time when the lower part of the prominence passed across the slit, and the sixth contains the height calculated from this.

I must state in regard to the velocities of ascent in the fourth column that no safe conclusions can be drawn from their differences, as they are a result of the uncertainty of the individual measures from which the figures were calculated. On trying to smooth out the data graphically I found that if corrections of at most $0^s.6$ are applied to the time of transit an entirely uniform ascent with constant velocity is obtained.

Such corrections are entirely justified by numerous transits of prominences, for it is not unusual for a single measure to differ from the mean of many transits by more than $0^s.5$. The assumption of a uniform ascent is unjustified, however, as the prominence is without doubt under the influence of gravity, and it must therefore sink at the time it is rising, unless it is impelled upward by some quite problematic continuous force. I have reduced the observed altitudes on the assumption of constant gravity with an acceleration of 270 meters, and again sought to smooth them

out graphically. I found that the observed times of transit would require a correction of $0^s.7$ in only one case in order to be in full agreement with this assumption. Hence it appears that the above observations, despite the capricious ascent, are by no means inconsistent with the assumption that the prominence is a mass of hydrogen projected from the Sun, which rises above the chromosphere with the velocity of empty space and is under the influence of gravity alone.

But, although we admit of uncertainties of $\pm 9''$ in the single determinations of transits—which would materially modify differences of height of $10''$ to $30''$—we obtain from the whole data the entirely reliable velocity of ascent of 334 km per second; the prominence rose $132''$ in $4^m\ 46^s$; an uncertainty of even $10''$ is of no consequence.

During the ascent of the prominence I also observed a large displacement of the lines of the spectrum, those from the central part of the mass being displaced toward the violet. A rapid setting of the micrometer thread indicated that this velocity was about 350 km per second.

The approaching dissolution was noted during the last transit; the smaller portions were invisible, and the larger somewhat faint and diffuse, unless possibly this was the effect of a temporary haziness of the sky. Three minutes later the entire brilliant prominence had disappeared; no trace of it could be any longer seen even far above the chromosphere. According to the notes made, the duration of the violent eruption would therefore be estimated at only fifteen minutes. This estimate is confirmed when we divide the altitude attained, 312,400 km, by the mean velocity of ascent, whereby we similarly obtain $15^m\ 35^s$.

The rapidity of the dissolution deserves special attention. Under the circumstances an accurate measure of the separate parts was impossible. If I take as a basis the dimensions from the scale of the drawing of the central part and assume that it actually dissolved in the three minutes, as stated above, then a temperature of 10,000° would not be sufficient—30,000° would be needed—to explain its dispersion into empty space in so short

a time. No difficulty is encountered here, nor is it generally met with in case of violent eruptions; but it arises in case of the low-hanging prominences, which dissolve so slowly that we should have to assume a temperature which is far too low.

This unusual phenomenon can be brought into relation with the condition of the solar surface, as a small Sun-spot, surrounded by an extended group of faculæ, was approaching the limb at that point. It is true that the spot was 19° distant on a great circle from the limb; but such eruptions do not commonly proceed from the spot itself, but from its neighborhood, and frequently at about the above distance from it. It is worthy of mention in this connection that after the passing of this remarkable phenomenon I also observed at position-angle 259° a very rapid ascent. At that point I found a very bright flame, inclined 60° toward the pole, therefore diverging from the region of the spots, the rapid rise of which led me to measure its height from minute to minute. It rose from 41″ to 80″ between $2^h\ 31^m$ and $2^h\ 37^m$, when the central portion faded and the vertex separated. But now a new flame of a similar sort rose from the part remaining on the chromosphere, ascended rapidly in the same direction, and finally divided into four parts. The rise between 41^m and $49^m.5$ was from 49″ to 135″; the former prominence, therefore, rose with a velocity of 70 km; the latter with 80 km. Rapid ascents of small flames are not unusual, but the elevation attained was remarkable. The coincidence of these last ascents with the great eruption at the same time in the same region of spots again confirms the view expressed years ago that the phenomena of the spot zone are due to a common cause acting at considerable depths within the Sun.

HAYNALD OBSERVATORY,
June 1900

FIELD OF THE REFLECTING TELESCOPE.

By S. C. REESE.

THE writer has made an investigation of the field of the reflecting telescope and has found that there is no field, plane or curved, on which the images of stars off the axis of the paraboloid are free from distortion. Reflectors of short focal length and large aperture accentuate the distortion of star images and have called special attention to the aberration in the focal plane. Tennant[1] some years ago made a thorough investigation of the form of images in that plane; but, so far as the writer knows, Tennant's results have not been generalized, nor has it been shown that there is no field of circular images (where by a circular image we mean, not a diffraction disk, but a single round blurred patch of light). If such a field as the last did exist it would be the size of the round images that would decide the advisability of an attempt to use it in photography, as a small distorted image is better for many purposes than a large circular image. In order to give the subject as general a treatment as seemed required the writer made use of the methods of Kirchhoff[2], changing them to adapt them to the problem in hand. The writer has tried to call attention to the various limitations made and in the cases where the aberration in only a single direction or a single plane is discussed has avoided as far as possible confusing such aberration with that of the general case. No numerical results are given, as the shape and size of the images are well known to those who have photographed with the reflector and used either plane or curved plates.

[1] TENNANT, "Notes on Reflecting Telescopes," *M. N.*, 47, 1886-7, pp. 244-256.

[2] KIRCHHOFF, "Zur Theorie der Lichtstrahlen," *Sitzungsberichte der königlich Preussischen Academie der Wissenschaften zu Berlin* 30, 641, June 22, 1882. This paper is republished in *Poggendorff's Annalen*, Neue Folge, 1883, 18, 663, and is used in a slightly different form in Kirchhoff's *Mathematische Optik*.

Since the source of light is at an infinite distance the wave incident on the mirror is plane and the motion at the point x, y, z, can be represented by the equation

$$\phi = A \cos\left(\frac{r_1}{\lambda} - \frac{t}{T}\right) 2\pi \,, \tag{1}$$

where λ is the wave-length and T the period of vibration of the light, and r_1 the perpendicular distance of the point x, y, z, from a fixed plane $\alpha_1 x + \beta_1 y + \gamma_1 z + p = 0$ parallel to the wave-front, but otherwise arbitrary.

Now, by the use of Kirchhoff's method and the application of Green's theorem[1] we find that the motion ϕ_0 resulting at x_0, y_0, z_0, from a reflection can in most general terms be represented by

$$4\pi\,\phi_0(t) = \int ds \left[\frac{\delta}{\delta N} \frac{A \cos\left(\frac{r_1}{\lambda} + \frac{t - \frac{r_0}{a}}{T}\right)}{r_0} - \frac{f\left(t - \frac{r_0}{a}\right)}{r_0} \right] , \tag{2}$$

where the integral is taken over the entire reflecting surface, and where f is defined by the equation

$$\frac{\delta\phi}{\delta N} = f(t) \,.$$

In this expression r_0 represents the distance from the point x, y z, to the point x_0, y_0, z_0, and a the velocity of propagation of light. The integral in (2) can be broken up into the two expressions

$$\int -\frac{1}{r_0^2} A \frac{\delta r_0}{\delta N} \cos\left(\frac{r_1 + r_0}{\lambda} - \frac{t}{T}\right) 2\pi ds$$

$$+ \int -\frac{2\pi}{r_0\lambda} \frac{\delta r_0}{\delta N} \sin\left(\frac{r_1 + r_0}{\lambda} - \frac{t}{T}\right) 2\pi ds \,.$$

Now, λ is an infinitesimal of the first order with respect to r_0; therefore, the first of these integrals becomes infinitesimal with respect to the second and we have to consider only

$$4\pi\,\phi_0(t) = \int -\frac{2\pi}{r_0\lambda} \frac{\delta r_0}{\delta N} \sin\left(\frac{r_1 + r_0}{\lambda} - \frac{t}{T}\right) 2\pi ds \,. \tag{3}$$

[1] KIRCHHOFF, pp. 644–646.

It is necessary that when a plane wave falls on a portion of a surface and is brought to a focus x_0, y_0, z_0, by reflection, that that portion of surface should be capable of having close contact with the surface of a paraboloid of revolution having the point x_0, y_0, z_0, for its focus.

Now, the paraboloid of revolution has the property that the distance of each one of its points from the focus equals the distance of that point from a fixed plane (which can be called the "director plane"). Hence, for the paraboloid of revolution the condition is satisfied

$$r_0 + r_1 = \zeta, \tag{4}$$

where r_0 and r_1 have the meanings given above and ζ is the perpendicular distance between the arbitrary plane spoken of above and the "director plane."

Relation (4) is necessary to the integration of equation (3) by the method of Kirchhoff. Setting $\frac{2\pi}{\lambda} = k$ and $-\frac{t}{T}2\pi = \delta$, and having regard to (4), we find that (3) becomes

$$4\pi\phi_0 = -\int \frac{k}{r_0}\frac{\delta r_0}{\delta N} \sin\,(k\zeta + \delta)\,ds\,. \tag{5}$$

If

$$G = -\frac{\frac{\delta r_0}{\delta N}}{r_0}$$

then

$$4\pi\phi_0 = k\int G \sin\,(k\zeta + \delta)\,ds\,, \tag{6}$$

which can be shown to be equal to

$$4\pi\phi_0 = -\left[\frac{dF}{d\zeta}\cos\,(k\zeta + \delta)\right]_{\zeta_0}^{\zeta_1} \tag{7}$$

where F is a function whose first derivative is continuous for values of ζ between ζ_0 and ζ_1.

Having obtained this integral, we can commence the discussion of the mirror formed of a paraboloid of revolution. The paraboloid referred to, a rectangular system of axes with the z axis corresponding to the axis of revolution, can be represented by the equation

$$x^2 + y^2 = 4az \tag{8}$$

or, referred to rectangular axes, of which the z axis is normal to the surface, the x axis tangent to a principal section, and the y axis is in the tangent plane perpendicular to both these, the equation of the paraboloid is

$$\cos^2\theta x^2 + y^2 + 2\sin\theta\cos\theta xz + \sin^2\theta z^2 - \frac{4a}{\cos\theta}z = 0\,, \tag{9}$$

where θ is the angle between the new z axis and the axis of the paraboloid. In forming this equation, since the normals of a figure of revolution intersect the axis, no assumption has been made which limits the generality. But if we now consider a small portion of the paraboloid we may take x and y so small that terms of higher than the second order[1] can be neglected, and the equation of the paraboloid becomes

$$\cos^3\theta x^2 + \cos\theta y^2 = 4az\,, \tag{10}$$

or

$$z = a_{11}x^2 + a_{22}y^2\,, \tag{11}$$

where $a_{11} = \dfrac{\cos^3\theta}{4a}$, $a_{22} = \dfrac{\cos\theta}{4a}$, and θ is the angle between the z axis and the axis of the paraboloid. This form (11) is of the greatest importance, as it will appear that for such portions of surface the pencil of reflected light has no faults other than that of pure astigmatism. We may put also

$$ds = dxdy\,. \tag{12}$$

For any determined value of θ the distance of the point x_0, y_0, z_0, toward which the wave converges, from the origin is

$$s_0 = \sqrt{x_0^2 + y_0^2 + z_0^2}\,. \tag{13}$$

The distance of the point x_0, y_0, z_0, from a neighboring point x, y, z, on the surface of the mirror is

$$r_0 = \sqrt{(x-x_0)^2 + (y-y_0)^2 + (z-z_0)^2}$$

which by the use of (11), (13), and the quantities

$$\alpha_0 = \frac{-x_0}{s_0}\,, \quad \beta_0 = -\frac{y_0}{s_0}\,, \quad \gamma_0 = -\frac{z_0}{s_0}\,, \tag{14}$$

[1] KIRCHHOFF, p. 653; Strehl, *Theorie des Fernrohrs* (Leipzig, 1894), p. 11.

becomes to terms of the third order

$$r_0 = s_0 + a_0 x + \beta_0 y + (a_{11}x^2 + a_{22}y^2)\gamma_0 +$$
$$\frac{1}{2s_0}[x^2(1 - a_0^2) - 2a_0\beta_0 xy + y^2(1 - \beta_0^2)] .$$

But

$$r_1 = p + a_1 x + \beta_1 y + \gamma_1 [a_{11}x^2 + a_{22}y^2] ,$$

where a_1, β_1, γ_1, are direction cosines of the normal to the arbitrary plane, therefore

$$\zeta = (s_0 + p) + \left(a_{11}\gamma_0 + a_{11}\gamma_1 + \frac{1 - a_0^2}{2s_0}\right)x^2 - \frac{a_0\beta_0}{s_0}xy$$
$$+ \left(a_{22}\gamma_0 + a_{22}\gamma_1 + \frac{1 - \beta_0^2}{2s_0}\right)y^2 , \tag{15}$$

or

$$\zeta = A_0 + A_{11}x^2 + 2A_{12}xy + A_{22}y^2 , \tag{16}$$

where

$$\left.\begin{aligned} A_0 &= s_0 + p \\ A_{11} &= a_{11}\gamma_0 + a_{11}\gamma_1 + \frac{1 - a_0^2}{2s_0} \\ A_{22} &= a_{22}\gamma_0 + a_{22}\gamma_1 + \frac{1 - \beta_0^2}{2s_0} \\ A_{12} &= -\frac{a_0\beta_0}{2s_0} \end{aligned}\right\} . \tag{17}$$

It can now be shown that the equation (7) takes the form

$$4\pi\phi_0 = -G\frac{\pi}{\sqrt{\mu_1\mu_2}}\cos(kA_0 + \delta) , \tag{18}$$

where μ_1 and μ_2 are the roots of the equation

$$(A_{11} - \mu)(A_{22} - \mu) - A_{12}^2 = 0 . \tag{19}$$

Now

$$\mu_1\mu_2 = A_{11}A_{22} - A_{12}^2 . \tag{20}$$

Whenever this product becomes zero the intensity of light becomes infinite and a focus is reached. The equation for determining the focus is, then,

$$\left[a_{11}\gamma_0 + a_{11}\gamma_1 + \frac{1 - a_0^2}{2s_0}\right]\left[a_{22}\gamma_0 + a_{22}\gamma_1 + \frac{1 - \beta_0^2}{2s_0}\right]$$
$$- \frac{a_0^2\beta_0^2}{2s_0^2} = 0 , \tag{21}$$

a quadratic equation in s_0.

Since γ_1 is the cosine of the angle the incident ray makes with the normal, and θ is the angle that the normal makes with the axis, then if C denotes the angle the incident ray makes with the axis of the paraboloid, we have the relation

$$\cos^{-1}\gamma_1 + \theta = C,$$

or

$$\gamma_1 = \cos(C - \theta). \tag{22}$$

To determine whether the foci for the same ray reflected at different parts of the mirror fall at the same place or different places it is necessary to consider only some particular cases. The aberration shown by these determines qualitatively what may be expected in the general case.

I. When the incident light is parallel to the axis of the paraboloid. In equation (10) $\theta = 0$ and in (17) $\gamma_1 = 1$. Hence (21) becomes

$$\left[\frac{1}{4a}\gamma_0 + \frac{1}{4a} + \frac{1-\alpha_0^2}{2s_0}\right]\left[\frac{1}{4a}\gamma_0 + \frac{1}{4a} + \frac{1-\beta_0^2}{2s_0}\right] - \frac{\alpha_0^2\beta_0^2}{4s_0^2} = 0. \tag{23}$$

For the vertex of the paraboloid

$$\alpha_0 = \beta_0 = 0 \quad \gamma = 1 \quad \therefore \quad s_0 = -a\ ;$$

that is, the focus of the light parallel to the axis incident at the vertex is at the geometrical focus of the paraboloid. The sign shows the reversed direction of the light. If in (21) we set $\beta_0 = 0$ (that is, consider only a principal section) and in (22) set $C = 0$, then since $\gamma_0 = \gamma_1$ and $\alpha_0^2 + \beta_0^2 + \gamma_0^2 = 1$ we have

$$\left[\frac{\cos^4\theta}{4a} + \frac{\cos^4\theta}{4a} + \frac{\cos^2\theta}{2s_0}\right]\left[\frac{\cos^2\theta}{4a} + \frac{\cos^2\theta}{4a} + \frac{1}{2s_0}\right] = 0,$$

or

$$s_0 = -\frac{1}{\cos^2\theta}\cdot a = -\frac{a}{\cos^2\frac{1}{2}\omega},$$

where ω is the angle between the reflected light and the axis of the paraboloid. This value of s_0 is the same as the distance of a point on a parabola from the geometrical focus,[1] so that we have here the proof that the light parallel to the axis of a parabola,

[1] See equation 6, Poor's "Aberration of Parabolic Mirrors," this JOURNAL, 7, 114, 1898.

and reflected from any point of the figure, comes to a focus at the geometrical focus of the figure.

II. When the incident light makes an angle C with the axis of the paraboloid. (1) When only the central part of the mirror is considered.

$$\gamma_0 = \gamma_1 = \cos C.$$

If we again consider a principal section we have $\beta_0 = 0$, and (21) becomes

$$\left[\frac{\cos C}{2a} + \frac{\cos^2 C}{2s_0}\right]\left[\frac{\cos C}{2a} + \frac{1}{2s_0}\right] = 0.$$

Then

$$s_0 = -a \cos C, \tag{24}$$

that is, the focus lies on the circle of diameter a through the vertex and focus (in the case of the solid this is a sphere), or

$$s_0 = -\frac{a}{\cos C}. \tag{25}$$

The second focus of the pencil lies on the line through the geometrical focus perpendicular to the axis (in case of the solid this is the focal plane).

The fact that the two foci do not fall together is an immediate consequence of the astigmatism of the pencil.

Between these two foci is the place of the circular image, which is not a true focus. For this to the first approximation[1]

$$s_0 = -\frac{a(1 + \cos^2 C)}{2 \cos C}. \tag{26}$$

The z's of the points given by (24), (25), and (26) are given by

$$\left.\begin{aligned} z &= -a \cos^2 C; && (27) \\ z &= -a; && (28) \\ z &= -\frac{a(1+\cos^2 C)}{2}; && (29) \end{aligned}\right\} \text{A}$$

while the x's are given by

$$\left.\begin{aligned} x &= -a \cos C \sin C; && (30) \\ x &= -a \tan C; && (31) \\ x &= -\frac{a(1+\cos^2 C)}{2}.\tan C. && (32) \end{aligned}\right\} \text{B}$$

[1] STREHL, *Theorie des Fernrohrs*, Article 11, p. 17.

(2) When the portion of the paraboloid on which the light falls normally is considered.

In equation (21)

$$\gamma_0 = \gamma_1 = 1\,, \quad a_{11} = \frac{\cos^3\theta}{4a}\,, \quad a_{22} = \frac{\cos\theta}{4a}\,.$$

If we again consider a principal section (which the coördinates we use allow us to take through the point of incidence), again $\beta_0 = 0$ and (21) becomes

$$\left[\frac{\cos^3\theta}{4a} + \frac{\cos^3\theta}{4a} + \frac{1-\alpha^2}{2s_0}\right]\left[\frac{\cos\theta}{4a} + \frac{\cos\theta}{4a} + \frac{1}{2s_0}\right] = 0\,. \tag{33}$$

But since

$$\alpha_0^2 + \beta_0^2 + \gamma_0^2 = 1\,, \quad \alpha_0 = 0\,.$$

Hence

$$s_0 = -\frac{a}{\cos^3\theta} \quad (34) \qquad \text{or} \qquad s_0 = -\frac{a}{\cos\theta}\,. \tag{35}$$

For circular images

$$s_0 = -\frac{a(1+\cos^2\theta)}{2\cos^3\theta}\,. \tag{36}$$

To find the z and x for each of these points we must use the formulae

$$\left.\begin{aligned} -z &= a\tan^2\theta + [s_0]\cos\theta\,,\\ -x &= -2a\tan\theta + [s_0]\sin\theta\,,\end{aligned}\right\} \tag{37}$$

where $[s_0]$ is the value of s_0 apart from sign.

The equations (34) (35), and (36) give

$$\left.\begin{aligned} z &= -a\tan^2\theta - \frac{a}{\cos^2\theta} && (38)\\ z &= -a\tan^2\theta - a\,, && (39)\\ z &= -a\tan^2\theta - \frac{a(1+\cos^2\theta)}{2\cos^2\theta}\,. && (40)\end{aligned}\right\}\ \mathrm{C}$$

$$\left.\begin{aligned} x &= 2a\tan\theta - \frac{a}{\cos^3\theta}\sin\theta\,, && (41)\\ x &= 2a\tan\theta - \frac{a}{\cos\theta}\sin\theta\,, && (42)\\ x &= 2a\tan\theta - \frac{a(1+\cos^2\theta)}{2\cos^3\theta}\sin\theta\,. && (43)\end{aligned}\right\}\ \mathrm{D}$$

From equations A, B, C, and D it can be proved that neither the foci nor the circular sections of the cones from the center of the

mirror and the portion where the light strikes normally will coincide except for $\theta = 0$; that is, for a mirror which is limited to the infinitesimal portion of surface at the vertex of the paraboloid.

(3) When the light making an angle C with the axis falls on a part of that principal section whose normal makes the angle θ with the axis.

$$\left[\frac{\cos^3\theta}{2a}\cos(\theta - C) + \frac{\cos^2(\theta - C)}{2s_0}\right]\left[\frac{\cos\theta}{2a}\cos(\theta - C) + \frac{1}{2s_0}\right] = 0 \quad (44)$$

$$s_0 = \frac{a}{\cos\theta\cos(\theta - C)}, \quad s_0 = \frac{a\cos(\theta - C)}{\cos^3\theta} .$$

The position of the circular image requires approximately that

$$s_0 = \frac{a\left[\cos^2\theta + \cos^2(\theta - C)\right]}{2\cos^3\theta\cos(\theta - C)} .$$

Taking the z's and x's of these points we find that for the foci or the circular image to coincide with those given by the portion of the paraboloid immediately around the vertex it is necessary that a relation should exist between C and θ, which shows that, in general, the light oblique to the axis and falling on any point of the mirror will not be brought to focus where the light which falls on the center part is condensed, nor will the circular images coincide. The interpretation of this result is found in this statement: That there does not exist any field, plane or curved, on which the image of the star off the axis is either a sharp diffraction disk (either round or linear) or a single blurred circle.[1] There seems, then, no way by use of curved plates to avoid the fan-shaped images[2] with an instrument having a large angular aperture. Very near the axis, of course, the distortion is negligible.

YERKES OBSERVATORY,
June 1900

[1] McLAREN, "On the images formed by reflecting mirrors and their aberration," *M. N.*, 47, 1886–7, p. 404, note.

[2] TENNANT, place cited.

Reviews

A GENERAL CATALOGUE OF 1290 DOUBLE STARS DISCOVERED FROM 1871 TO 1899 BY S. W. BURNHAM.[1]

ASTRONOMERS have known for a number of years that Mr. Burnham has been engaged in collecting measures and other material for the formation of a general catalogue of the double stars. Such a catalogue is indispensable to all double star observers and at present none exists in print.

This work in manuscript form has been patiently kept abreast of the times and has been in a condition for publication for many years, but its appearance has been prevented by a lack of means to print it. It is the only general catalogue of double stars in existence—except that of Innes', which deals alone with the southern stars. The work is a very large and complete one, consisting of twelve manuscript volumes covering the measures and history of every known double star from the north pole to 31° of south declination.

That Mr. Burnham has expended his best energies for a quarter of a century in its compilation is a complete guarantee of its very high value. It has not yet been possible to get the money to print this most important work and it still lies in manuscript form in his office, where double star observers throughout the world are constantly forced to apply for information on the subject of double stars.

Perhaps it was not known to many that Mr. Burnham had also another special general catalogue of double stars, always kept up to date in manuscript, but of less extent than the greater catalogue, for it contained only his own discoveries of double stars which had been made by him at various times and with a most varied assortment of telescopes. This most complete history of nearly 1300 double stars, many of which are among the most interesting and important yet discovered, after lying for many years in his office in Chicago, has at last assumed the form of a very handsome quarto volume admirably printed by the University of Chicago Press.

[1] *Publications of the Yerkes Observatory of the University of Chicago*, Volume I, University of Chicago Press, 1900.

Perhaps no other gift of the late Miss Catherine W. Bruce was of more direct benefit to astronomy than the publication of this volume, for it is to her generosity that astronomers are indebted for the printing of this splendid work. The volume is No. I of the *Publications of the Yerkes Observatory* and consists of 288 pages, with an appendix of six pages more containing the latest observations of Burnham's stars, which were received too late for insertion in the body of the work. The title is: *A General Catalogue of 1290 Double Stars, Discovered from 1871 to 1899, by S. W. Burnham.*

The work is handsomely illustrated with half tone cuts of the Lick, the Yerkes, and the Dearborn telescopes, not omitting the famous 6-inch, now at the University of Wisconsin. A beautiful half tone cut of the Yerkes Observatory forms the frontispiece and numerous diagrams illustrate the orbits of the more interesting of the double stars.

To one who has so often heard Mr. Burnham affectionately speak of Baron Dembowski, that most skillful observer, the dedication of the present volume is almost pathetic in its language, for Dembowski was the first one to recognize and encourage the struggling amateur:

TO THE MEMORY OF
BARON DEMBOWSKI
THE DISTINGUISHED DOUBLE STAR OBSERVER, THE FIRST TO UNDER TAKE THE SYSTEMATIC MEASUREMENT OF THESE STARS, AND WHOSE KINDLY CRITICISM AND GENIAL ENTHUSIASM WERE TO THE WRITER ALWAYS AN INSPIRATION
THIS VOLUME
IS GRATEFULLY INSCRIBED

That Mr. Burnham's gratitude has kept fresh through all the years is further shown in his remarks in the introduction, which as they touch upon an observer who is so little known generally, except to double star observers, are worthy of transcription here.

I was fortunate in being placed in communication with this eminent astronomer soon after the commencement of my work with the 6-inch refractor, and from that time on until his death in 1881, I was in constant correspondence with him, and all of my discoveries were transmitted to him in advance of their publication. These new stars were measured by him in the most painstaking and thorough manner, and his observations give the fundamental data for comparison with subsequent measures of many of the most important of these new systems. As an observer with the micrometer he had no superior, and few if any equals. His work is of the highest degree of accuracy. He made no mistakes and wasted no time in idle speculations.

He has left a record of honest, thorough, and consistent work, which will be an honor to his memory for all time. Baron Dembowski was to me an example so inspiring, a critic so genial and frank, a friend so warm hearted and disinterested that simple justice as well as friendship impels me to inscribe this volume to his memory.

The introduction contains an admirable and concise historical account of Mr. Burnham's early work and is highly instructive.

After trying several small telescopes with object-glasses of foreign make, he finally, about 1869, arranged with Alvan Clark & Sons for a 6-inch refractor, stipulating only that it should be the best they could make.

This telescope soon became famous from the discovery of difficult double stars, and doubtless did more to give the Clarks their high prestige than any other instrument they ever turned out, excellent though they always were.

With this instrument Mr. Burnham discovered 451 new double stars, many of which were difficult objects in far greater telescopes. These discoveries were made after the sky had been swept over by the best double-star observers with much more powerful telescopes. This fact, however, Mr. Burnham modestly attributes to the superior defining power of his telescope. Though doubtless many of these stars depended on that very defining power for their detection, it is hardly necessary to state that it was mainly due to the unexcelled skill of the observer himself that they were found. Without the man — the right man — the best instrument is useless. Indeed, in this very connection there is nothing more instructive in the literature of astronomy than the account, quoted by Mr. Burnham in the volume, of Mitchel's visit to Sir James South in 1842, when seeking information for a large refractor for the Cincinnati Observatory. Mitchel's own account of his visit runs thus:

> One apartment was examined after another, until finally we reached a large room surmounted by a dome of great size and of an expensive construction, while fragments of the framework for mounting a great equatorial were scattered around.
>
> "Here, sir," exclaimed Sir James, "you behold the wreck of all my hopes. Here I have expended thousands, and flattered myself that I was soon to possess the finest instrument in Europe, but it is all over, and there's an end."
>
> I remarked that the object-glass was still in his possession, and might yet be mounted, so as to realize his hopes and expectations.

"No," said Sir James. "Struve has reaped the golden harvest among the double stars, and there is little now for me to hope or expect."

It would be difficult to appreciate the feelings which at that moment were sweeping through the mind of the astronomer. Long-cherished visions of fame and high distinction, nay, perhaps of grand discoveries in the heavens, which for years had played around his hopes of the future, had fled forever. Another had reaped the golden harvest, and like Clairaut, who wept that there was not for him, as for Newton, the problem of the universe to solve, Sir James South could almost weep to think that another's eye had been permitted to sweep over the far distant realms of space which he had long hoped might remain his own peculiar province.

The instrument referred to was a 12-inch refractor.

Perhaps it is not out of the way to add here that Sir James South was so disappointed with the delay in the finishing of his mounting, the unsatisfactory condition in which it was finally furnished him, and the consequent loss of the chance for discovery that, as if to more fully accentuate these lost chances, it is said, he finally hired a healthy and vigorous blacksmith and a heavy sledge hammer to smash up and utterly destroy all of the telescope with the exception of the object-glass itself, which he finally gave away. This was over a quarter of a century before the advent of the celebrated 6-inch!

Mr. Burnham's high opinion of the Clark object-glasses is frequently shown in the volume as, for instance, in the case of *85 Pegasi* (p. 269): "It is an excellent test for the definition of any object-glass, however large, and no instrument, whatever its aperture, can deal with a pair of this class unless the figure of the objective will compare favorably with the Alvan Clark standard." And this is very true indeed.

Mr. Burnham is very cautious and makes few or no mistakes. A beautiful confirmation of his accuracy has but just occurred, at a time too when he himself was somewhat shaken in his own faith. In 1871 he found with the 6-inch that the companion to Rigel was a very close double (pp. 59, 60); the star appeared elongated in the small instrument. He subsequently saw and measured it with the 18½-inch at Chicago, in 1878. From 1879 to 1898, with the single exception of an observation by the Henry Brothers at Paris, in 1884, the star was apparently single in all instruments; even the 36-inch at Mount Hamilton failed to show it, though it was under observation for four or five years. The repeated failures to even elongate the star with the most powerful instruments gave the impression that some mistake must have been made in the early observations with the smaller instruments. In

the very passing of the proofs of this catalogue through the press, Mr. Burnham had written (p. 60). "One of two conclusions seems obvious, either this star is not double at all, the elongation supposed to be seen on the different occasions mentioned being due to atmospheric or other causes; or, if double, it must be moving with great rapidity. The negative results can be explained in no other way. I dislike to believe that I have been deceived by any spurious elongation of the small star, as this would be the first time such a mistake has happened in my experience in double-star observations; but certainly my subsequent failures to see this star double would tend to that conclusion."

It remained thus until November of 1898, when Aitken, who had watched it at Mr. Burnham's request with the 36-inch, again found it to be double, but excessively close and difficult. It has since been seen with the 40-inch of the Yerkes Observatory. Mr. Burnham thinks that possibly this star may have a shorter period than that of any known binary.

Of late years Mr. Burnham has frequently shown the absurdity of many of the computed double-star orbits. In several cases he has shown that a straight line would as faithfully represent the observations as any of the orbits that had been computed from them. As an illustration of his keen insight into the problems of double-star motion, we may take the case of *9 Argus*, *β* 101 (pp. 92, 93, 94). This star was known to be a binary, and an orbit had been computed for it with a period of over forty years. In 1892 Mr. Burnham, by a judicious selection of observations, computed a new orbit with a period of 23.3 years. This differed entirely from the previous one in all the elements. So strong was his faith in the correctness of the orbit that he unhesitatingly predicted that in the two years following his measures of 1892, the star would move through more than 180° of its orbit, a prediction which was fully confirmed by the great rapidity of the star's motion at that time.

It is not only his good judgment, but also his knowledge of the fallibility of many observers that enables him to discriminate and reject unreliable observations, and thus avoid the pitfalls that come to the average computer, who must take all observations on faith and construct an orbit not only to fit the accurate measures, but to fall in with the poor ones as well. In work of this kind there is nothing like knowing the proper value to put on the available material, and especially in knowing where to prune out without mercy, and this characteristic seems to be highly developed in Mr. Burnham.

His remarks about telescopes are always good, and a comparison of his 6-inch with some of the larger instruments, that preceded it in double star work, must be interesting. In this particular he says:

But it must be remembered that at least some of the instruments used by these observers could not compare favorably with modern refractors, and particularly with telescopes made by the Clarks; and even when these observers had more powerful instruments in point of light-grasping power, as in the case of the Herschels, there can be no doubt that they were far inferior in definition, and in every practical respect for observations of this kind, to the 6-inch refractor. . . . . A glance at the list of old pairs to which new and more difficult components have been added will be sufficient on this point. I have shown in the appendix to my thirteenth catalogue that my several lists which had been published at that time included more double stars of Class I (where the distance does not exceed 1″) than all the various catalogues of both Herschels and both Struves, notwithstanding the fact that the works of these eminent astronomers contain altogether not less than 7400 double stars.

The arrangement of the catalogue is an admirable one and should serve as a model for all such work. The salient facts concerning each star are given in the briefest yet most comprehensive form. An excellent index to the different stars is found at the close of the volume, from which any one of the objects can at once be found in the body of the work.

Mr. Burnham pays a just tribute to Aitken of the Lick Observatory, who has furnished him with a very large number of measures of these stars up to the moment of issuing the volume, and which are of high importance, giving, as they do, the very latest information of many of the stars.

In the catalogue there are 18 quadruple stars of the ϵ *Lyrae* type, but while the distance between ϵ^1 and ϵ^2 *Lyrae* is about 207″, the greatest distance between any of the pairs in this catalogue does not exceed half that amount, and the closest of these pairs is not separated by more than 11″.

The catalogue contains a large percentage of the shortest period binaries, including the celebrated κ *Pegasi*, whose period, 11.37 years, is the shortest known.

The observations show that there are no less than 185 β stars which are binaries, and doubtless many times that number will be shown to be physically connected pairs when sufficient time has elapsed. Of

these, 27 pairs certainly have periods of less than 50 years and 5 have periods ranging between 15 and 30 years, such as

β 101, *9 Argus*	23.3 years
β 733, *85 Pegasi*	25.7 years
β 151, *β Delphini*	26.7 years

whose orbits were computed by Mr. Burnham. He shows that β 883 does not have the short period of 5½ years assigned it by one computer. He further shows that at present the data are not sufficient to definitely determine the period of this star, though he concludes that Glasenapp's period of 16.35 years, determined from observations up to 1891, is near the truth.

Perhaps one thing as striking as any other in the volume is the evident care each one of the stars receives. The proper motion is given in every case where possible. All the measures of the different components, if the star happens to be a new member of an old system, are given. Mr. Burnham has exhausted every known source for proper motion, and in many instances has been able to supply this from his own measures. The proper motions are very valuable, for though no relative motion should be shown in a double star, it yet may be known to be a binary by the common proper motion of its components. Several hundred cases of proper motion are given. As so many of these stars are not only of the highest interest, but are also extremely difficult objects, they have engaged the attention of the best observers in this class of work with the finest instruments yet made. This volume, therefore, containing the observations of these stars, has an additional interest from this point of view alone.

The history of each star is briefly given in tabular form, including the measures of the different components, if it is a multiple star. Outside of the actual importance of these measures for orbit investigation, it is a most interesting summary, as it shows side by side the work of the different observers; those who have passed away are linked to the present generation by their work on these stars. Take, for example, the quadruple system of *ν Scorpii* (pp. 148, 149). There seems to be no certain evidence of change in any of the components of this star since their discovery. For the star *C*, measures are given from 1782, of *D*, from 1846, and of *A* (β 120), from 1874. The first of these stars has been measured by six observers, including William Herschel; the second by thirteen, and the third by fifteen observers. In all,

twenty individual observers have measured one part or the other of this multiple star in the past one hundred and fifteen or twenty years. Each one has had his try at it and his measures remain to us as an evidence of his skill. They all show, however, the remarkable fixity of the system of *ν Scorpii*, which remains immutable while the observers come and go. Comparing this star with *9 Argus* about 1892 to 1894 we have essentially the extremes of double star movements.

Mr. Burnham points out a remarkable case of proper motion in connection with *Aldebaran* (pp. 49, 50, 51). A new companion to this star was found by him in 1877 with the 18½-inch at Chicago. The measures show that this small star has the same proper motion as *Aldebaran*, and it is therefore a physical companion; while the old 11th magnitude companion discovered by Herschel over a hundred years ago, and which Mr. Burnham found to be double in 1888, has a proper motion apparently independent of *Aldebaran*, and hence seems to be an independent system of its own seen in the direction of *Aldebaran*. Such proper motion in so small a star is remarkable, and it would almost seem, in spite of the evidence given, that it is also a physical companion to the large star, and that the difference of proper motion is really due to orbital motion of the smaller star.

When it is known that the great number of measures in this volume made by Mr. Burnham himself is not the largest part of the great mass of measures of double stars he has made during a very busy life, having in general no connection with astronomy whatever, it will be seen that he has wasted none of the time at his disposal for telescopic work. To accomplish all this he has had to work much faster than the average observer. His measures are made very rapidly, so that he usually spends only a few minutes with a star. The time is further abbreviated by his singular method of recording. He always makes three settings of the wires before recording them in his notebook, mentally carrying each successive reading until the three are made, and these are then written down. His notes are sometimes put down in stenographic characters, for he was once an expert stenographer.

Perhaps no other observer has used such a varied assortment of telescopes. Beginning with the 6-inch, or still earlier, with a 3-inch, he has not only used for measuring, but has discovered double stars with the 6-inch, 9.4-inch, 12-inch, 15½-inch, 16-inch, 18½-inch,

26-inch, 36-inch, and finally with the great 40-inch of the Yerkes Observatory.

This is shown by the following tabulation of the number of double stars discovered with each instrument (p. xi).

With the

6 -inch — Private Observatory	451
18½-inch — Dearborn Observatory	413
36 -inch — Lick Observatory	198
15½-inch — Washburn Observatory	87
9.4 -inch — Dartmouth College Observatory	24
26 -inch — Naval Observatory	14
40 -inch — Yerkes Observatory	8
16 -inch — Warner Observatory	2

Among these powerful instruments it is pleasing to see that the greatest number of discoveries with any one telescope was made with the 6-inch. One somehow takes far greater pride in this, for it represents the labor of a struggling amateur, who during the day led the drudging life of a stenographer in the United States court in Chicago, and at night worked among the stars for the pure love of it. Such work deserves an everlasting fame, and surely this has fallen to Mr. Burnham.

E. E. BARNARD.

Photometric Revision of the Harvard Photometry during the Years 1891–1894. By EDWARD C. PICKERING. *Annals of the Astronomical Observatory of Harvard College*, Vol. XLIV, Part I. Cambridge, 1899.

THE measures forming the original *Harvard Photometry* were made during the years 1879–1882 with the small meridian photometer. When the large meridian photometer, aperture 10.5 cm, was returned from Peru, a revision of these measures was undertaken, and the present important volume gives the result of this revision, together with measures of comparison stars for variables and miscellaneous objects, about 7000 in all.

On examining this work one is struck with the condensed form in which the results are given. Several columns found in the *Harvard Photometry* (*HP*) are omitted; the first four columns give, successively, the *DM* number of the star, the right ascension and declination for

1900, and the *DM* magnitude. As the *HP* number is not given, and the epoch is twenty years later than for the star-places in the *HP*, reference to the latter work is rendered less convenient, but the saving in space is quite justified. The next three columns give in succession the mean photometric magnitude, the Julian day of each observation, and the corresponding residual, found by subtracting the mean from the several results. In this condensed form, the date and magnitude from each day's measures can be found, a very important point, in case variability is later suspected.

The number of observations of each star is generally three, though in many cases it is considerably increased, sometimes reaching forty. For the comparison stars for variables the number is frequently two.

A complete discussion of the results in this volume, giving comparisons with other photometric catalogues, would be of great interest, and will doubtless appear in a later volume of the Harvard *Annals*. In the meantime it seemed worth while to the writer to make a partial comparison with the *Harvard Photometry* (*HP*) and the *Potsdam Photometric Durchmusterung* (*PDM*). For this purpose every twenty-fifth star in the *HP* was taken, numbers 1, 26, 51, 76, etc. It was found that 165 of these stars were contained in the volume under discussion, which will be called the *Revision* (*Rev*), and of these eighty-five fell within the limits of the *PDM*. On comparing the *Revision* with the *Harvard Photometry*, the mean difference in the sense *Rev*—*HP* was found to be $+0^m.012$, showing that the systems in the two volumes are practically identical. The mean difference, without regard to sign, was $\pm 0^m.131$. The distribution of the differences is shown in the following table:

Range in $0^m.01$	Number of residuals
0 to 4	38
5 " 9	37
10 " 14	35
15 " 19	19
20 " 24	14
25 " 29	7
30 " 34	5
35 " 39	4
40 " 44	5
> 44	1

The greatest difference was for *HP* No. 2776 $-0^m.59$. This star has four observations in the *HP* and five in the *Rev*.

The comparison with the *Potsdam Photometric Durchmusterung* (*PDM*) gave similar results. Of the sixty-six stars common to each the mean difference was found to be, *HP—PDM* = — $0^m.206$; *Rev–PDM* = — $0^m.189$. Although this depends on a relatively small number of stars, it is shown to be fairly representative by the fact that in Part II of the *PDM*, page 456, all the stars common to it and the *HP* gave difference *HP—PDM* = — $0^m.18$. Adding the constant $0^m.18$ to the differences, the means became as follows:

HP—PDM = — $0^m.024$; *Rev—PDM* = — $0^m.008$

The differences without regard to sign then became:

HP—PDM = $\pm 0^m.18$; *Rev—PDM* = $\pm 0^m.16$

A considerable part of these latter residuals is doubtless due to systematic differences in the measurement of stars of different colors, as is shown by Müller and Kempf in *PDM*, II, 459 (see also ASTROPHYSICAL JOURNAL, **10**, 70).

The only typographical error noticed is the declination of ϵ *Eridani* (*HP* 576), which is given as north in the *Revision*. J. A. P.

ERRATA.

ASTROPHYSICAL JOURNAL, Vol. XII, No. 1. In title of Plate VIII, *for* 6½ feet Focal Length *read* 61½ feet Focal Length.

Vol. XII, No. 2, p. 163, line 25. *For* enlarged 22 diameters *read* enlarged 2.2 diameters.

THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOL. XII NOVEMBER, 1900 NO. 4

The ASTROPHYSICAL JOURNAL is published monthly except in February and August. Annual subscription, $4.00; foreign, 18 shillings. *Wm. Wesley & Son, 28 Essex Street, Strand, London*, are sole foreign agents and to them all European subscriptions should be addressed. All papers for publication and correspondence relating to contributions and exchanges should be addressed to *George E. Hale, Yerkes Observatory, Williams Bay, Wisconsin, U. S. A.* All correspondence relating to subscriptions and advertisements should be addressed to *The University of Chicago Press, Chicago, Ill.* All remittances should be made payable to the order of the *University of Chicago*.

[Entered at the Post Office at Chicago, Ill., as second-class mail matter.]

THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME XII NOVEMBER, 1900 NUMBER 4

JAMES EDWARD KEELER.

By W. W. CAMPBELL.

It is a painful duty to record the death of Professor Keeler, on August 12, in the forty-third year of his life. The announcement came as a great shock to colleagues and friends widespread, who had seen before him a career of rarest promise. A feeling of grievous loss is borne upon us. As an investigator in astrophysics, there was no one more successful. As a director, there were none more ideal. As a companion, who was more delightful? His premature death involves a loss to astronomy and to the Lick Observatory which is incalculable.

James Edward Keeler was born in La Salle, Illinois, on September 10, 1857, of a long line of New England ancestry. The family removed to Mayport, Florida, in 1869, where Keeler prepared, by private study, for entering college. Here he acquired his fondness for astronomical observation. He established "The Mayport Astronomical Observatory" in 1875–1877 It included a quadrant, with which he observed the altitude of *Polaris* in 1875; a two-inch achromatic telescope, which he first directed to the planets and the nebulæ in December 1875; a clock, and a meridian circle, which he himself constructed and

mounted in 1877. [Keeler's original sketch of the meridian circle, and his written description of it, will be published in the *Publications of the Astronomical Society of the Pacific.*]

Keeler's "Record of Observations made at the Mayport Observatory" contains beautiful colored drawings of Jupiter, Saturn, Venus, and Mars, of double stars, and of portions of the Moon, in addition to data of a numerical character. These early sketches are worthy forerunners of his well-known drawings of many of the same objects in later years.

Mr. Keeler entered Johns Hopkins University late in the year 1877; and, following major courses in physics and German, he was graduated with the degree of A.B. in 1881.

Evidences of the high esteem in which Keeler was held by his instructors are not lacking. He largely defrayed his expenses in college by acting as assistant to some of the lecturers in the experimental courses. His private journal modestly relates the details of an evening lecture on electricity, delivered by him to a circle of young people, in President Gilman's residence. At the end of his freshman year, he accompanied Professor Hastings, as a member of Professor Holden's party from the Naval Observatory, to observe the total solar eclipse of July 29, 1878, at Central City, Colorado. His part was the modest one of making a drawing of the corona. The preliminary practice for this work, the precautions taken, and the conveniences provided, are described in his report, which is a model of scientific writing. In the spring of 1881, Professor Langley requested the Johns Hopkins University to recommend a suitable man for the position of assistant in the Allegheny Observatory. Keeler was named for and accepted the appointment, beginning work several weeks before receiving his degree. In June 1900, one of the physicists who had recommended Keeler for the Allegheny position was speaking to me of this very appointment and said: "I told Professor Langley that one of my strongest reasons for the recommendation is that Keeler doesn't claim to know everything." To the end of his life this charming trait remained unimpaired.

Professor Langley made his noted expedition to the summit of Mount Whitney, California, in the summer of 1881, to determine the value of the "Solar Constant." Mr. Keeler accompanied the expedition in the capacity of assistant, and carried out his share of the program with skill and efficiency. His work at Allegheny during the next two years was closely related to the problems arising from this expedition.

The year 1883–4 was devoted to study and travel in Europe. During the summer semester he attended lectures by Quincke, Bunsen, and Fuchs at Heidelberg. During the winter semester, in Berlin, he heard the lectures on physics by Helmholtz and Kayser, on differential equations by Runge, and on quaternions by Glan. In the Berlin physical laboratory he investigated the "Absorption of Radiant Heat by Carbon Dioxide," a problem suggested, no doubt, by his Mount Whitney experiences.

From June 1884, to April 1886, Mr. Keeler again served as assistant in the Allegheny Observatory. He afforded most efficient help to Professor Langley in his well-known researches on the lunar heat and on the infra-red portion of the solar spectrum.

Early in 1886, Mr. Keeler was appointed assistant to the Lick Trustees. He reached Mount Hamilton on April 25, and at once proceeded to establish the time service. The telegraph line to San Jose was perfected, the transit instrument, the clocks, and the sending and receiving apparatus were installed. The daily time signals were sent over the lines of the Southern Pacific Railway Company on and after January 1, 1887, north to Portland, east to Ogden, and south to El Paso. He remained in personal charge of this service until June 1891.

When the Observatory was completed and transferred to the Regents of the University of California, on June 1, 1888, Mr. Keeler was appointed to the position of Astronomer, and placed in charge of the spectroscopic work. The large spectroscope constructed for the Observatory, mainly from his designs, is an extremely efficient and convenient instrument; for visual observations it has no superior. This instrument was used with great

success in many kinds of spectroscopic work. He confirmed Vogel's observations as to the absence of telluric absorption in the spectrum of Saturn's rings. His observations of the spectrum of Uranus confirmed and extended the results obtained by Huggins and Vogel. He secured a long series of observations of the bright and dark lines in the spectra of γ *Cassiopeiae* and β *Lyrae.* He made an accurate determination of the color curve of the 36-inch objective, which is of very frequent use. His beautiful observations of the spectra of the Orion nebula and thirteen planetary nebulae mark a distinct epoch in visual spectroscopy; and his classical memoir[1] on the subject should be familiar to all spectroscopic observers. In these observations a Rowland plane-grating, 14,438 lines to the inch, was employed, in connection with the 36-inch telescope. The wave-lengths of the bright nebular lines were measured in the third and fourth order spectra—taking advantage of the fact that, other things being equal, high dispersion does not weaken the brightness of a monochromatic bright line. The wave-lengths of the principal nebular line in the fourteen nebulæ were found to vary from 5007.86 t. m. in *N. G. C.* 5790 to 5005.97 t. m. in *G. C.* 4373, with an average probable error for each object of only 0.04 t. m. The discrepancies were attributed to differences in the relative velocities of the nebulæ with reference to the solar system. The velocities themselves could not be determined directly, since the normal wave-length of the principal line was unknown, and there was no known method of reproducing this line artificially. Fortunately, the third line, hydrogen β, was bright enough in the *Orion* nebula to be compared directly with terrestrial hydrogen. The mean result of thirteen sets of such comparisons gave, for the velocity of the nebula, a recession from the solar system of 17.7 ± 1.3 kilometers per second. Correcting the observed wave-lengths of the principal line by the corresponding displacement, its normal wave-length was found to be λ 5007.05 t. m. A comparison of the observed wave-lengths of the line in the thirteen planetary nebulæ with

[1] *Publications of the Lick Observatory*, 3, 161–231.

the normal wave-length gave their velocities with reference to our system. Their values lay between –65 and + 48 kilometers. The average probable error of the velocity obtained for each nebula, depending on all the measures, was only ± 3.2 kilometers per second. The important fact was established that the velocities of the nebulæ are of the same order of magnitude as the velocities of the stars.

In a similar manner the normal wave-length of the second nebular line was found to be λ 4959.02.

Among the first objects observed with the 36-inch telescope were the planetary nebulæ and their stellar nuclei. The observers noticed that the focal length for a nebula is about 0.4 inch longer than for its stellar nucleus: a discrepancy which Professor Keeler at once explained by recalling that the star's light is yellow, whereas that of the nebula is greenish-blue. This appears to be the first recognition of the fact that a great refracting telescope is also a powerful spectroscope, for certain classes of objects, by virtue of the chromatic aberration of its objective [*Mon. Not. R. A. S.*, for 1888, p. 389; *Astr. Nach.* No. 3111].

Professor Keeler's faithful and artistic drawings of Jupiter, made in 1888–1890, with the assistance of the 36-inch equatorial, have no equals.

Professor Keeler resigned from the Lick Observatory staff on June 1, 1891, to succeed Professor Langley as Director of the Allegheny Observatory and Professor of Astrophysics in the Western University of Pennsylvania. His investigations there fully maintained the splendid reputation established for the Observatory by his predecessor. He comprehended the possibilities and limitations of his situation, and adapted himself to them. His spectroscopic researches were largely confined to the orange, yellow, and green regions of the spectrum, since they would be less strongly affected by the smoky sky for which that vicinity is famous.

The Allegheny spectroscope, constructed from his designs in 1891–2, contains a number of valuable improvements. The

ease with which it may be converted from a three-prism to a one-prism, or to a grating spectroscope, commends the plan to all. The use of three simple prisms is a departure which has been followed with advantage in many later instruments.

We may mention three noteworthy series of observations made with this instrument.

An extensive investigation of the Orion nebula and the stars immersed in it established the fact that nearly all the bright lines in the nebular spectrum have corresponding dark lines in the stellar spectra, and thus that the nebula and stars are closely related.[1]

Keeler's observations of the spectrum of Saturn's rings are of extraordinary interest. Considering the means at hand, they have never been surpassed in excellence or beauty. The classic researches of Clerk Maxwell on the composition of the rings, leading to the conclusion that they must be a cluster of little moons revolving in circular orbits, found their worthy counterpart in Keeler's spectrographic proof that every point in the ring system is moving with the velocity which a moon would have if situated at that distance from the planet. Let us not forget that these observations were made with a 13-inch telescope, in a smoky sky, which restricted the photographs to the low dispersion of the green region of the spectrum.

Professor Keeler's main piece of work at Allegheny, on the spectra of Secchi's third type stars, remains unpublished, but the measures and reductions are left in an advanced stage.

Professor Keeler was appointed to the position of Director of the Lick Observatory on March 8, 1898. He entered upon his new duties on June 1, 1898.

Without making any rearrangement of the work of the existing staff, but giving every encouragement to continue along the same lines, Professor Keeler arranged to devote his own observing time to the Crossley reflector. The story of the wonderful success with this difficult instrument is familiar to all the readers

[1] Simultaneous observations of the same objects at another observatory led to the same conclusion.

of the ASTROPHYSICAL JOURNAL. He was quick to recognize that this instrument was not in condition to produce satisfactory results. He proceeded energetically to make one change after another, and to overcome one difficulty after another, until at the end of five months he was ready to submit it to trial. On November 14, he secured a splendid negative of the Pleiades, and on the 16th a superb negative of the Orion nebula. Having satisfied himself of the enormous power of the reflector in nebular photography, he entered upon the program of photographing the brighter Herschel nebulæ. More than half of the subjects on his program have been satisfactorily photographed. The Observatory possesses a set of negatives of the principal nebulæ which is priceless, and unequaled.

These photographs record, incidentally, great numbers of new nebulæ. A conservative estimate places the number within reach of the Crossley reflector at 120,000.

It had previously been supposed that the great majority of nebulæ were irregular in form, and that only a few were spirals. These photographs have recorded more spiral nebulæ than irregular ones. This discovery bears profoundly upon the theory of the cosmogony, and must be considered as of the first order.

It is time to speak of Professor Keeler's work as Director. I but faintly reflect the views of every member of the staff, and, indeed, of all who have been interested in the work of the Lick Observatory, when I say that his administration was completely successful. He cherished and promoted ideal conditions in this ideal place. He made a success of his own work, in a splendidly scientific manner; and he saw to it that everyone had every possible opportunity to do the same. No member of the staff was asked to sacrifice his individuality in the slightest degree. Nor were demands made for immediate results. The peace of mind of the investigator, so absolutely required for complete success, was full and undisturbed. Withal, Professor Keeler's administration was so kind and so gentle—and yet so effective—that the reins of government were seldom seen and never felt.

The elements of his successes are simple, and plainly in view. His openness and honesty of character, his willingness and quickness to see the other man's point of view, his strong appreciation of the humorous, as well as the serious, and, above all, his abounding good sense—these traits made his companionship delightful and charming.

Scientifically, Professor Keeler never groped aimlessly in the dark. He would not attack a problem until he had as fully as possible comprehended its nature, and the requirements for success. With the plan of attack completely considered, the execution of his plans usually involved little loss of time. The Crossley reflector has afforded a case in point. It was seldom necessary for him to repeat any part of his work.

His published papers have a completeness, a ripeness, and a finish rarely seen. A complete list of his published writings is appended.

The honorary degree of Sc.D. was conferred upon Professor Keeler in 1893 by the University of California. The Rumford Medal was bestowed upon him in 1898 by the American Academy of Arts and Sciences, and the Henry Draper Medal in 1899 by the National Academy of Sciences. He was a member of the National Academy of Sciences; an Associate of the American Academy of Arts and Sciences; a Fellow and Foreign Associate of the Royal Astronomical Society; a Fellow of the American Association for the Advancement of Science; a member and officer of the Astronomical and Astrophysical Society of America; an honorary member of the Toronto Astronomical and Physical Society; the president of the Astronomical Society of the Pacific; a member of the Washington Academy of Sciences; and various other organizations. He was an associate editor of *Astronomy and Astro-Physics* during 1893 and 1894, and editor (with Professor George E. Hale) of the ASTROPHYSICAL JOURNAL from 1895 to the time of his death.

It appears that he had been a mild sufferer from heart weakness for many years. It is feared that on Mt. Hamilton he worked beyond his strength. His weakness seems to have

developed rapidly this year: a cold contracted in June he could not throw off. He left the Observatory on July 30, with no anxiety, to secure medical treatment in San Jose, and to spend a prospective vacation in northern California. Increasing difficulty in breathing led him to seek skilled assistance in San Francisco, on August 10. The dangerous condition of his heart was realized on the next day; and on the twelfth a stroke of apoplexy proved fatal.

It is known that Professor Keeler had planned his work with the Crossley Reflector far into the future. It is sad to relate that a small spectrograph, which he was most anxious to employ on certain interesting objects, was completed on the day of his leaving the Observatory. Arrangements have been made for carrying out his program.

The absence of one so old in experience and so ripe in judgment will be most seriously felt at the Lick Observatory, and throughout the profession.

Professor Keeler married Miss Cora S. Matthews, at Oakley Plantation, Louisiana, on June 16, 1891. Of her great sorrow, and of the grievous loss to the two children, it would be futile to speak. Their departure leaves the mountain inexpressibly sad.

PUBLISHED WRITINGS OF JAMES EDWARD KEELER.

Published writings chronologically arranged (title, publisher, date; in case of periodical literature, date, volume and page).

Report on the Total Solar Eclipse of July 29, 1878. *Washington Observations*, 1876.

The Transit of *Venus* of December 6, 1882. *Sidereal Messenger*. Vol. I, p. 292, 1883.

On Repolishing optical Surfaces of Rock Salt. *Ibid.*, Vol. V, p. 222, 1886.

The Absorption of Radiant Heat by Carbon Dioxide. *Am. Jour. Science*, September 1884.

Article "Bolometer." *Encyclopædia Britannica*, supplement.

The Time Service of the Lick Observatory. *Sidereal Messenger*, September and October 1887.

Electrical Contact Apparatus for Astronomical Clocks. *Sidereal Messenger*, January 1888.

First Observations of *Saturn* with the 36-inch Equatorial of the Lick Observatory. *Sidereal Messenger*, February 1888.

The 36-inch Equatorial of the Lick Observatory. *Scientific American*, June 16, 1888.

Micrometer Observations of the Satellites of *Mars*. *Astronomical Journal*, August 23, 1888.

Recent Astronomical Work at the Lick Observatory. *Scientific American*, November 10, 1888.

Observations of the Satellites of *Mars*. *Astronomical Journal*, No. 178, pp. 73–78.

The Appearance of *Saturn* in the 36-inch Equatorial of the Lick Observatory. *Ciel et Terre*, No. 21, January 1889, p. 514.

The outer Ring of *Saturn*. *Ciel et Terre*, No. 3, April 1889; *Astronomical Journal*, Vol. VIII, p. 175.

Report on the Total Solar Eclipse of January 1, 1889. In the *Lick Observatory Report*, p. 31.

On the Spectra of *Saturn* and *Uranus*. *Astronomische Nachrichten*, No. 2927.

Occultation of *Jupiter*, 1889, September 3. *Astronomical Journal*, Vol. IX, p. 84.

On the Establishment of a Standard Meridian Line for Santa Clara County, Cal. *Pub. A. S. P.*, No. 4, p. 65.

A new form of Electric Control for Equatorial Driving Clocks. *Pub. A. S. P.* Vol. II, p. 3.

The Physical Aspect of *Jupiter* in 1889. *Himmel und Erde*, 1890. (See *Pub. A. S. P.*, Vol. II, p. 15).

On the Chromatic Aberration of the 36-inch Equatorial. *Pub. A. S. P.*, Vol. II, p. 160.

White Spots on the Terminator of *Mars*. *Pub. A. S. P.*, No. 10, September 13, 1890.

The following briefer notes have been printed in the *Pub. A. S. P.*

No. 3—July 27, 1889, On Photographing the Corona in full Sunshine.

No. 3—July 27, 1889, Spectrum of Davidson's Comet.

No. 4—September 28, 1889, Notes on Stellar Spectra.

No. 7—March 29, 1890, List of Earthquakes in California during 1889.

No. 8—May 31, 1890, Notes on the Spectroscopic Apparatus of the Lick Observatory.

No. 10—September 13, 1890, The Chromatic Aberration of the Pulkowa 30-inch Refractor.

Earthquakes in California in 1889. *Bull. U. S. Geological Survey*, No. 68. Washington, 1890.

Observations of the Satellites of *Mars*. *Ast. Jour.*, No. 228.

Spectroscopic Observations of *Spica* at Potsdam. *Pub. A. S. P.*, Vol. III, p. 46.

Elementary Principles Concerning the Efficiency of Spectroscopes for Astronomical Purposes. *Sid. Mess.*, Vol. X, p. 433.

Annual Reports of the Director of the Allegheny Observatory. *Catalogues of the Western University of Pennsylvania*, 1891–1897.

The Star Spectroscope of the Lick Observatory. *Astronomy and Astro-Physics*, Vol. II, p. 140.

Principles elementaires concernant l'emploi du spectroscope pour les recherches astronomiques. *Bull. Astronomique*, Vol. IX, p. 4.

The Nebular Hypothesis. *Pub. Acad. Sci. and Art of Pittsburg*, 1892; *Astronomy and Astro-Physics*, Vol. II, p. 567.

On the Central Star of the Ring Nebula in *Lyra*. *Ast. Nach.*, No. 3111, *Astronomy and Astro-Physics*, Vol. II, p. 824.

Occultation of *Mars*, September 3, 1892. *Astronomy and Astro-Physics*, Vol. II, p. 831.

Observations of the Partial Solar Eclipse of 1892, October 20, *Ast. Jour.*, No. 277.

Do Large Telescopes Pay? *Astronomy and Astro-Physics*, Vol. II, p. 927.

The Spectrum of Holmes' Comet. *Ibid.*, Vol. II, p. 929.

The Spectroscope of the Allegheny Observatory. *Ibid.*, Vol. XII, p. 40; London *Engineering*, May 12, 1893.

Spectrum of Holmes' Comet. *Astronomy and Astro-Physics*, Vol. XII, p. 27.

Visual Observations of the Spectrum of *Lyrae*. *Ibid.*, Vol. XII, p. 350.

Note on the Spectrum of *P Cygni*. *Ibid.*, Vol. XII, p. 361.

Observations of Comet b 1893. *Ibid.*, Vol. XII, p. 650 and p. 751.

The Wave-lengths of the Two Brightest Lines in the Spectrum of the Nebulae. *Ibid.*, Vol. XII, p. 733.

The Spectroscope and Some of Its Applications. *Popular Astronomy*, Vols. I and II, 1893–4.

Spectroscopic Observations of Nebulae, made at Mount Hamilton, California, with the 36-inch Refractor of the Lick Observatory. *Pub. Lick Observatory*, Vol. III, Part 4, Sacramento, 1894.

Professor Lockyer's Researches on Stellar Spectra. *Astronomy and Astro-Physics*, Vol. XIII, p. 59.

Chromatic Aberration of Telescopes. *Ibid.*, Vol. XIII, p. 157.

A Comparison of Drawings and Photographs of *Jupiter*. *Jour. British Ast. Association*, Vol. IV, p. 358.

On the Spectra of the Orion Nebula and the Orion Stars. *Astronomy and Astro-Physics*, Vol. XIII, p. 476.

The Magnesium Spectrum as an Index to the Temperature of the Stars *Ibid.*, Vol. XIII, p. 660; *A. N.*, No. 3245.

Professor Frost's Translation and Revision of *Die Spectralanalyse der Gestirne*. *Astronomy and Astro-Physics*, Vol. XIII, p. 688.

The Advantage of the Short-Focus Camera in Spectrum Photography. *Ibid.*, Vol. XIII, p. 772.

The Use of the Short-Focus Camera in Stellar Spectrum Photography. *Ibid*, Vol. XIII, p. 857.

On a Lens for Adapting a Visually Corrected Refracting Telescope to Photographic Observations with the Spectroscope. *Astrophysical Journal*, Vol. I, p. 101; *Trans. Ast. and Phys. Soc.*, Toronto, 1894.

Schmidt's Theory of the Sun. *Astrophysical Journal*, Vol. I, p. 178.

The Design of Astronomical Spectroscopes. *Ibid.*, Vol. I, p. 248.

"The Source and Mode of Solar Energy Throughout the Universe" (Review). *Ibid.*, Vol. I, p. 269.

Photographic Correcting Lens for Visual Telescopes. *Ibid.*, Vol. I, p. 350.

The Displacement of Spectral Lines Caused by the Rotation of a Planet, *Ibid.*, Vol. I, p. 352.

A Spectroscopic Proof of the Meteoric Constitution of *Saturn's* Rings. *Ibid.*, Vol. I, p. 416.

Spectroscopic Observations of *Saturn* at the Allegheny Observatory. *West. Univ. Courant*, April 1895; *Pop. Astr.*, Vol. II, p. 443.

Spectroscopic Observations of *Saturn* at the Allegheny Observatory. *Science*, May 10, 1895; *Pub. A. S. P.*, Vol. VII, p. 154; *Observatory*, Vol. XVIII, p. 227.

Conditions Affecting the Form of Lines in the Spectrum of *Saturn*. *Astrophysical Journal*, Vol. II, p. 63.

Picturing the Planets. *Century Magazine*, July 1895.

Note on the Spectroscopic Proof of the Meteoric Constitution of *Saturn's* Rings. *Astrophysical Journal*, Vol. II, p. 163.

Photographs of the Spectrum of the Ball and Rings of *Saturn*. *Mon. Not. Roy. Ast. Soc.*, Vol. LV, p. 474.

Note on a Cause of Differences Between Drawings and Photographs of Nebulae. *Pub. A. S. P*, Vol. XVII, p. 279.

Note on the Rotation of *Saturn's* Rings. *Ast. Nach.*, No. 3313.

Physical Observations of *Mars*, made at the Allegheny Observatory in 1892. *Memoirs Roy. Ast. Soc.*, Vol. LI, p. 45.

Recent Researches Bearing on the Determination of Wave-Lengths in the Infra-Red Spectrum. *Astrophysical Journal*, Vol. III, p. 63.

"Recherches spectrales sur l'étoile *Altair*" (Review). *Ibid.*, Vol. III, p. 78.

Test of the Forty-inch Objective of the Yerkes Observatory. *Ibid.*, Vol. III, p. 154.

"On the Photographic Spectrum of the Great Nebula in *Orion*" (Review). *Ibid.*, Vol. III, p. 229.

Proposed Methods of Applying the Object-Glass Prism to the Measurement of Stellar Motions. *Ibid.*, Vol. III, p. 311.

The Detection of the Lines of Water-Vapor in the Spectrum of a Planet. *Ibid.*, Vol. IV, p. 137.

"New Books on the Spectroscope" (Review). *Ibid.*, Vol. IV, p. 156.

Measurement by Means of the Spectroscope of the Velocity of Rotation of the Planets. *British Association Reports*, Liverpool Meeting, 1896, p. 729.

Photographic Studies of the Moon at the Paris Observatory. *Astrophysical Journal*, Vol. V, p. 51.

The Lick Obseratory Atlas of the Moon. *Ibid.*, Vol. V, p. 150.

Spectroscopic Observations of *Mars* in 1896–7. *Ibid.*, Vol. V, p. 328.

The X-Ray Apparatus of the Academy of Science and Art of Pittsburgh. *Pub. Acad. Sci. and Art of Pittsburgh*, 1897.

On the Mode of Printing Maps of Spectra and Tables of Wave-Lengths, *Astrophysical Journal*, Vol. VI, p. 144.

The Importance of Astrophysical Research and the Relation of Astrophysics to other Physical Sciences. Address delivered at the Dedication of the Yerkes Observatory. *University of Chicago Record*; *Astrophysical Journal*, Vol. VI, p. 271; *Science*, November 19, 1897.

Spectra of Stars of Secchi's Third Type. *Astrophysical Journal*, Vol. VI, p. 423.

Some Notes on the Application of Photography to the Study of Celestial Spectra. *Photographic Times*, May 1898.

The Hydrogen Atmosphere surrounding the Wolf-Rayet Star *D.M.* 30° 3639. *Astrophysical Journal*, Vol. VIII, p. 113, 1898.

Photographic Observations of Comet i, 1898 (Brooks), made with the Crossley Reflector of the Lick Observatory. *Astronomical Journal*, No. 451, Vol. XIX, p. 151, 1898.

Observations of the Leonids, made at the Lick Observatory, University of California. *Astronomical Journal*, Vol. XIX, No. 451, p. 152.

The Small Bright Nebula near *Merope*. *Pub. A. S. P.*, Vol. X, p. 245, 1898.

Photographs of Comet i, 1898 (Brooks). *Ibid.*, Vol. X, p. 252.

Report of the Director of the Lick Observatory. *Biennial Report of the President of the University of California*, 1896–1898, p. 31.

Variations in the Spectrum of the *Orion* Nebula. *Astronomische Nachrichten*, No. 3541.

Color Phenomena attending the Earth's Shadow at Sunset. *Popular Astronomy*, Vol. VII, p. 98, 1899.

The Influence of Physiological Phenomena on Visual Observations of the Spectrum of the Nebulae. *Pub. A. S. P.*, Vol. X, p. 141, 1898.

Photographs of Comet i, 1898 (Brooks), made with the Crossley Reflector of the Lick Observatory. *Astrophysical Journal*, Vol. VIII, p. 287, 1898.

Photograph of the Great Nebula in *Orion*, taken with the Crossley Reflector of the Lick Observatory. *Pub. A. S. P.*, Vol. II, p. 39, 1899.

On some Photographs of the Great Nebula in *Orion*, taken by means of the less Refrangible Rays in its Spectrum. *Astrophysical Journal*, Vol. IX, p. 133, 1899.

Some Photographs of the Orion Nebula which are directly comparable with Drawings. *Pub. A. S. P.*, Vol. II, p. 70, 1899.

Note on the New Form of Photographic Telescope proposed by Professor Pickering in *H. C. O. Circular*, No. 39. *Astrophysical Journal*, Vol. IX, p. 269, 1899.

A National Observatory. *Science*, Vol. IX, p. 476, 1899.

Small Nebulae discovered with the Crossley Reflector of the Lick Observatory. *Mon. Not. R. A. S.*, Vol. LIX, p. 537, 1899.

Reply to an Article by Professor Scheiner. *Ibid.*, Vol. X, p. 167, 1899.

The Annular Nebula *H. IV 13* in *Cygnus*. *Ibid.*, Vol. X, p. 266, 1899.

The Annular Nebulae in *Lyra* and *Cygnus*. *Pub. A. S. P.*, Vol. II, p. 177, 1899.

On the Predominance of Spiral Forms among the Nebulae. *Astronomische Nachrichten*, No. 3601.

The Photographic Efficiency of the Crossley Reflector. *Pub. A. S. P.*, Vol. II, p. 199; *Observatory*, Vol. XXII, p. 437; *Popular Astronomy*, Vol. VIII, p. 4, 1900.

Reply to Professor Scheiner's Criticisms in *A. N. 3593*, of certain observations of the Nebula in *Orion*, made at the Lick Observatory. *Astronomische Nachrichten*, No. 3601, 1899.

New Nebulae discovered photographically with the Crossley Reflector of the Lick Observatory. *Mon. Not. R. A. S.*, Vol. LX, p. 128.

The Scientific Work of the Lick Observatory. *Science*, November 10, 1899.

Reply to a letter by Professor Hill. *Science*, January 12, 1900.

The Spiral Nebula *H I, 55 Pegasi*. *Astrophysical Journal*, Vol. II, p. 1, 1900.

Observations of Leonids at the Lick Observatory in 1899. *Astronomical Journal*, No. 474, Vol. XX, p. 148.

Photographic Observations of Hind's Variable Nebula in *Taurus*, made with the Crossley Reflector of the Lick Observatory. *Mon. Not. R. A. S.*, Vol. LX, p. 424, 1900.

Discovery and Photographic Observations of a New Asteroid, 1899 FD. *Astronomische Nachrichten*, No. 3636, 1900.

Use of the Crossley Reflector for Photographic Measurements of Precision, *Pub. A. S. P.*, Vol. XII, pp. 73, 74, 1900.

The Crocker-Lick Observatory Eclipse Expedition. *Ibid.*, Vol. XII, pp. 74, 75, 1900.

The Mexican Earthquake of January 19th observed at the Lick Observatory. *Ibid.*, Vol. XII, pp. 37, 38, 1900.

Photograph of the Trifid Nebula in *Sagittarius*. *Ibid.*, Vol. XII, pp. 89, 90, 1900.

A Handbook of Astronomical Instruments (Review of Ambronn's *Handbuch der Astronomischen Instrumentenkunde*). *Ibid.*, Vol. XII, pp. 117–121, 1900.

Discovery of a New Asteroid, 1899 FD., with the Crossley Reflector. *Pub. A. S. P.*, Vol. XII, pp. 126, 127, 1900.

Preliminary Account of the Results obtained by the Crocker Eclipse Expedition of the Lick Observatory. *Ibid.*, Vol. XII, p. 130, 1900.

The Crossley Reflector of the Lick Observatory. *Astrophysical Journal*, Vol. XI, pp. 325–349, 1900.

A LIST OF NINE STARS WHOSE VELOCITIES IN THE LINE OF SIGHT ARE VARIABLE.

By W. W. CAMPBELL and W. H. WRIGHT.

THE following nine spectroscopic binaries, discovered with the Mills spectrograph, are additional to the sixteen already announced.

The results expressed in integers are only approximate, and in most cases will be slightly changed by the final measures and reductions.

12 PERSEI ($\alpha = 2^h\ 36^m$; $\delta = +39°\ 46'$).

The binary character of this star was discovered in January, from the second spectrogram. The spectra of both components are visible on the first three plates, and are not very unlike. On the last plate the two spectra appear to be coincident.

Date			Velocities
1899	Dec.	19	−42 km and ± 0 km
1900	Jan.	22	− 3 " − 54
	Jan.	26	−11 " − 43
	Aug.	7	−27

The velocity of the system is about −25 km per second.

ξ URSAE MAJORIS ($\alpha = 11^h\ 13^m$; $\delta = +32°\ 06'$).

The principal component of this well-known double star has a variable velocity in the line of light. ξ *Ursae Majoris* is therefore a triple system. The visible system is interesting, historically, as having been the first one to show orbital motion, the two visible components forming a close and rapidly revolving system ($a = 2\overset{''}{.}5, P = 60$ years). It has been observed with the micrometer very frequently since the beginning of the century, but no evidences of perturbative influences have been revealed by the measurements.

	Date	Velocity
1897	Feb. 23	− 8.4 km
	April 8	−15
1899	Feb. 22	−11.5
	April 5	−14.1
1900	Feb. 26	−21.9
	Mar. 9	−18.4
	Mar. 12	−19
	Mar. 14	−21.6
	Mar. 20	−20
	May 8	−18

The variable velocity was discovered early in March, from the fifth plate.

The spectrograms obtained in 1897 are rather poor, and will probably not be needed in the final discussion of the motion.

93 LEONIS ($\alpha = 11^h 43^m$; $\delta = +20° 46'$).

The first two plates of this star were underexposed, but the discordance of eight kilometers afforded strong suspicion of its variable velocity. Two late plates confirmed the fact of its variability.

	Date	Velocity
1900	Jan. 10	+22 km
	Jan. 16	+14 ±
	Apr. 9	−16
	May 14	+16

d BÖOTIS ($\alpha = 14^h 06^m$; $\delta = +25° 34'$).

	Date	Velocity
1900	Mar. 27	+79 km
	April 4	+ 3
	April 9	+11
	April 17	+60 ±

The variable velocity was discovered from the second plate

β SCUTI ($\alpha = 18^h 42^m$; $\delta = -4° 51'$).

	Date	Velocity
1899	May 15	−17 km
	June 11	−11
1900	April 17	−28
	April 23	−29
	May 14	−32
	July 18	−31

The variable velocity was discovered from the third plate.

113 HERCULIS ($\alpha = 18^h\ 50^m$; $\delta = +22°\ 32'$).

Date		Velocity
1900	June 5	−35 km
	July 9	−21
	July 17	−19
	July 31	−16

The variation was discovered from the second plate,

2 SCUTI ($\alpha = 18^h\ 37^m$; $\delta = -9°\ 09'$).

Date		Velocity
1899	June 14	−49 km
	June 19	−50
	July 3	−45
1900	June 27	−40
	July 3	−38
	Aug. 1	−49
	Aug. 12	−38

The lines in this star's spectrum are rather broad, and cannot be measured very accurately. In addition, the third plate was underexposed; and the range of five kilometers in the approximate results for the first three plates afforded only a slight suspicion of vriability. Its reality was established from the fourth plate.

η ANDROMEDAE ($\alpha = 0^h\ 52^m$; $\delta = +22°\ 52'$).

Two components seem to be visible in the spectrograms of this star. The results for the principal component are:

Date		Velocity
1899	Oct. 24	−25 km
	Oct. 31	−26
1900	July 24	−12
	Aug. 8	+ 2
	Sept. 9	− 2

The two component spectra appear to be practically coincident in the spectrogram of 1900, July 24.

κ PEGASI ($21^h\ 40^m$; $\delta = +25°\ 11'$).

It will be recalled that this is the visual binary star having the shortest known period ($a = 0''.4$, $P = 11$ years). It was

discovered by Burnham in 1880 with the 18½-inch telescope, and is one of the difficult stars on his list. The two components are described as yellowish, and of magnitudes about 4½ and 5. The present distance of the components is less than 0″.2, in position angle 260° ±. It is not possible to photograph their spectra separately with the Mills spectrograph.

One of the components of this double star—probably the component whose spectrum is the stronger in the $H\gamma$ region—is a spectroscopic binary. *κ Pegasi* is therefore a triple system of great interest. The observations secured are as follows:

Date		Velocity
1896	Aug. 31	−43 km
1899	July 17	−41
1900	Aug. 6	+35
	Aug. 7	+27
	Aug. 8	−16
	Aug. 12	+35
	Aug. 21	−45
	Aug. 22	−34

The variable velocity was discovered from the third plate. The period seems to be about six days.

Changes in the appearance of the spectrum occur, but their source has not yet been traced.

[NOTE BY W. W. C.—Mr. Wright was in charge of the work with the Mills spectrograph during my connection with the Crocker Eclipse Expedition to Georgia, from March to late in July. While following the regular program of observation, he detected the variable velocities of the stars *ξ Ursae Majoris*, *d Böotis*, *β Scuti*, *113 Herculis*, and *2 Scuti*, as described above; and the credit for these five discoveries belongs to him.]

LICK OBSERVATORY,
UNIVERSITY OF CALIFORNIA,
September 12, 1900.

THE VISIBLE SPECTRUM OF *NOVA AQUILAE.*

By W. W. CAMPBELL.

THE new star in *Aquila*, discovered by Mrs. Fleming in July 1900; by means of its spectrum on the Draper Memorial photographs, was observed by Mr. Wright and myself on the evening of August 27. A 60° simple prism spectroscope was used in connection with the 36-inch refractor.

The visible spectrum consisted of extremely faint continuous light in the green, and of three bright bands in the positions of the three principal nebular lines. The relative intensities of the three bands agreed approximately with the corresponding intensities in the well-known nebular spectra. The bands were not monochromatic, but on the contrary were very broad, perhaps fully twice as broad as the bands in the nebular spectrum of *Nova Aurigae* in August 1892.

The present observations confirm the Harvard College Observatory observations that the spectrum of *Nova Aquilae* is nebular.

September 17, 1900.

THE VARIABLE STAR *7792 SS CYGNI.*

THIRD PAPER, 1899–1900.

By J. A. PARKHURST and ZACCHEUS DANIEL.

THE past year's observations of this variable star (discovered by Miss Wells from the Harvard photographs, and announced in *H. C. O. Circular* No. 12) have revealed several interesting points in its manner of variation, some of them as unexpected as they were remarkable. After two and a half years of alternating "long" and "short" maxima of the same general type, differing only in duration, the star violated all traditions by passing a maximum of an entirely different type, whose reality might be doubted were it not for the fact that it was attested by the accordant results of four different observers. This was followed by two "long," one "short," and one "long" maximum, of the ordinary type, closing the chapter at the date of writing. We have no record like this in the annals of variable-star work.

The former papers in this series[1] covered the interval between December 1896 and January 1899. The present paper continues the work till August 1900, using the same comparison stars (with one exception) and light scale which are given in Table I. In this table, following the letter and the coördinates of the star from the variable, there are three columns headed "Magnitude." In the first column, headed "Vis." are given the magnitudes on the visual scale, defined by agreement with the photometric scale at 8.0 magnitude, and the assumption of 12.8 as the limit of the 6-inch reflector. The next column gives the photometric magnitudes of nine of the stars, kindly supplied by Professor E. C. Pickering, and the third column the *B. D.* magnitudes of such of the stars as are contained in that catalogue. Table II gives the reduction from the visual to the photometric scale, using the magnitudes of the

[1] *Popular Astronomy*, 6, 156 and 7, 138.

visual scale as the argument. The accompanying chart, Fig. 1, shows the stars within 1 minute of the variable in R. A. and 10′ in Declination.

TABLE I.

COMPARISON STARS FOR *7792 SS CYGNI.*

R. A. $21^h\ 38^m\ 46^s.2$, Dec. + 43° 7′ 35″ (1900).

Star	Coör. from V.		Magnitude			B. D. No.
	R. A.	Dec.	Vis.	Phot.	B. D.	
	s					
k	+ 3.5	— 0.8	12.4			
h	— 8.0	— 1.1	11.81			
o	+ 3.8	+ 5.4	11.58	12.14		
q	— 5.1	— 5.3	11.44			
g	— 30.7	— 2.4	11.41			
m	— 5.9	+ 4.2	11.30	11.77		
e	— 34.8	— 0.7	10.86			
d	— 14.5	— 1.4	10.55	10.92		
p	+ 19.5	+ 6.4	10.54	10.90		
n	— 7.6	+ 7.7	10.51			
a	— 21.3	— 1.0	9.43	9.62	9.2	+ 42°4186
c	+ 0.3	+ 8.0	9.27	9.39	9.2	43 4020
s	— 55	+ 27	9.07		8.7	43 4012
w	+ 100	+ 13.3	8.86	8.90	8.6	43 4030
b	+ 27.0	— 0.2	8.46	8.50	8.3	42 4190
l	+ 123	— 8.7	7.92	8.00	8.5	42 4195

TABLE II.

REDUCTION FROM VISUAL TO PHOTOMETRIC SCALE.

Visual Scale	Reduction
8.0	0.0
9.0	+ 0.13
10.0	+ 0.28
11.0	+ 0.45
12.0	+ 0.66

In Table III we have given the observed magnitudes between February 10, 1899, and August 3, 1900. For economy of space only the Julian dates are given in the first column, the decimals

being in Greenwich Mean Time. In the second and third columns, headed Vis. and Ph., are given the magnitudes by the visual and photometric scales, respectively, followed by a colon when the observation was doubtful. In the fourth column is

R. A. $21^h\ 38^m\ 46^s$, Dec. $+43°\ 7'.6$ (1900).

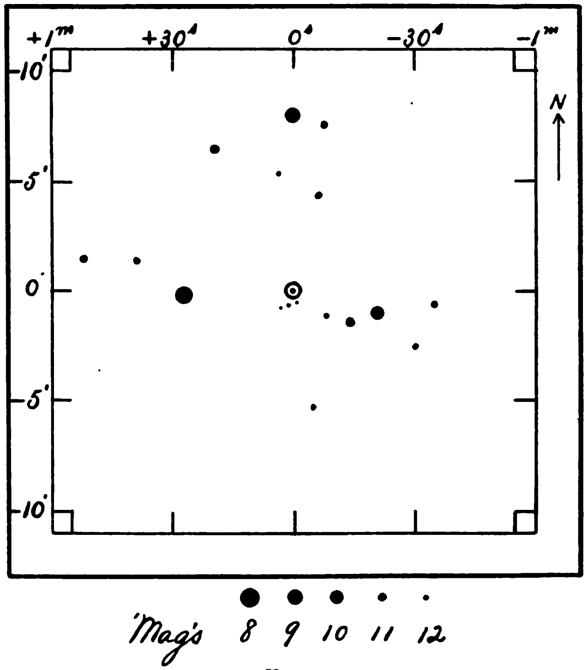


Fig. 1.

the initial of the observer. The table contains 286 observations. Of these 131 were made by Daniel, 71 with the 10-inch Clark refractor of the Bucknell Observatory at Lewisburg, Pa., and 60 with his 4-inch refractor. Of Parkhurst's 155 observations, 149 were made with his 6-inch reflector, 5 with the Yerkes 12-inch, and 1 with the Yerkes 40-inch refractor. In spite of this variety of instruments, the magnitudes are quite accordant, the simultaneous observations usually agreeing within 0.1 magnitude.

TABLE III.

OBSERVED MAGNITUDES OF *7792 SS CYGNI.*

D = Zaccheus Daniel, P = J. A. Parkhurst.

Julian Day	Magnitude		Obs.	Julian Day	Magnitude		Obs.
	Vis.	Ph.			Vis.	Ph.	
2414696.53	11.44	11.98	D	2414841.68	8.66	8.75	D
4702.00	11.37	11.89	P	42.65	8.93	9.05	P
18.96	11.3 :	11.8 :	P	42.67	8.81	8.91	D
19.95	11.26:	11.76:	D	44.65	9.10	9.24	P
20.97	10.90	11.33	P	45.63	9.24	9.40	P
21.96	8.41	8.46	P	45.64	9.11	9.25	D
26.96	9.83	10.08	P	46.63	9.65	9.88	P
33.96	11.30	11.81	P	46.67	9.35	9.53	D
55.89	11.37	11.89	D	47.62	9.65	9.88	P
61.92	11.37	11.89	P	47.65	9.73	9.97	D
66.92	11.40	11.93	P	48.65	10.15:	10.46:	D
74.72	11.37:	11.89:	D	50.71	11.05	11.51	D
76.70	9.50	9.70	P	53.62	11.15	11.63	P
76.90	9.24	9.40	P	53.64	11.16	11.64	D
77.90	8.50	8.56	P	54.62	11.15	11.63	P
79.67	8.25	8.28	P	56.60	11.25	11.75	P
81.71	8.46	8.52	D	68.67	11.22	11.71	D
84.66	8.34	8.38	D	72.60	11.37	11.89	P
85.88	8.86	8.97	P	73.65	11.37	11.89	D
86.67	8.58	8.66	D	76.64	11.37	11.89	P
88.65	8.95	9.07	D	77.63	11.28	11.79	P
90.67	9.56	9.77	D	79.60	11.35	11.87	P
93.65	10.79	11.20	P	79.64	11.32	11.83	D
4796.87	11.44	11.98	P	80.58	11.20	11.69	P
4804.65	11.36	11.88	P	81.60	11.26	11.76	P
08.65	11.32	11.84	D	82.59	11.18	11.67	P
09.65	11.34	11.86	P	83.58	11.26:	11.76:	P
13.66	11.34	11.86	P	84.58	11.23	11.73	P
18.65	11.39	11.92	P	85.58	11.30	11.81	P
18.71	11.30:	11.81:	D	86.58	11.30	11.81	P
21.63	11.20	11.69	P	87.58	11.30	11.81	P
22.64	11.37	11.89	D	88.59	11.30	11.81	P
25.64	11.3 :	11.8 :	P	89.57	10.55	10.92	P
26.64	11.30:	11.81:	D	89.60	10.36	10.70	P
27.62	11.4 :	11.9 :	P	90.57	8.63	8.71	P
29.63	11.44	11.98	P	91.58	8.50	8.56	P
30.65	11.39	11.92	P	93.58	8.51	8.57	P
35.63	11.44	11.98	P	95.58	8.50	8.56	P
35.66	11.37	11.89	D	96.58	8.53	8.60	P
36.67	11.13	11.61	D	97.58	8.60	8.68	P
36.71	11.34	11.86	P	4899.58	8.71	8.80	P
37.65	10.45	10.80	D	4901.58	8.89	9.00	P
38.62	8.45	8.51	P	02.60	8.85	8.96	P
38.63	8.66	8.75	D	04.58	9.55	9.76	P
39.67	8.61	8.69	D	06.60	10.77	11.17	P
40.67	8.61	8.69	D	09.59	11.22	11.71	P
2414841.67	8.63	8.71	P	2414909.67	11.30	11.81	D

TABLE III.—*Continued.*

Julian Day	Magnitude		Obs.	Julian Day	Magnitude		Obs.
	Vis.	Ph.			Vis.	Ph.	
2414928.53	11.34	11.86	D	2414995.54	9.92	10.18	D
28.56	11.30	11.81	P	96.51	10.22	10.53	P
30.55	11.28	11.79	P	97.51	10.85	11.27	P
32.57	11.33	11.85	P	97.57	10.51	10.87	D
35.5	11.30	11.81	P	4998.50	11.03	11.49	D
37.56	11.4 :	11.9 :	P	5001.66	11.37	11.89	D
40.63	11.37	11.89	P	02.54	11.37	11.89	D
42.66	11.44	11.98	D	04.54	11.52	12.07	D
46.54	11.37	11.89	P	05.60	11.42	11.95	D
46.66	11.44	11.98	D	08.51	11.35	11.87	P
48.66	11.42	11.95	D	08.52	11.58	12.15	D
49.54	11.33	11.85	P	09.51	11.32	11.83	P
49.64	11.44	11.98	D	10.58	11.44	11.98	P
50.64	11.37	11.89	D	12.53	11.28	11.79	P
51.54	11.26	11.76	P	14.50	11.44:	11.98:	P
51.65	11.37	11.89	D	16.51	11.32	11.83	P
52.50	10.87	11.29	P	17.51	11.32	11.83	P
52.55	10.95	11.39	P	18.51	11.21	11.70	P
52.65	10.91	11.34	D	21.51	8.71	8.80	P
56.54	8.60	8.68	P	22.51	8.65	8.74	P
57.51	8.86	8.96	P	23.51	8.55	8.62	P
57.60	8.79	8.89	D	24.51	8.50	8.56	P
58.54	9.09	9.23	P	25.50	8.50	8.56	P
59.50	9.18	9.34	P	26.55	8.46	8.52	D
61.67	9.99	10.27	D	27.51	8.52	8.59	P
62.58	10.55	10.92	P	28.51	8.65	8.74	D
63.52	10.88	11.31	P	29.54	8.85	8.95	D
64.50	11.23	11.73	P	30.54	8.83	8.93	D
65.52	11.20	11.69	P	32.51	8.93	9.05	D
65.61	11.16	11.64	D	41.51	11.37:	11.89:	D
67.53	11.16	11.64	P	42.52	11.30:	11.81:	P
79.54	11.25	11.75	P	44.51	11.25	11.75	P
82.56	10.32	10.65	D	47.53	11.37:	11.89:	D
83.50	9.99	10.27	D	51.52	11.30	11.81	P
84.50	9.85	10.11	D	52.52	11.37	11.89	D
84.50	10.05	10.34	P	53.51	11.32	11.83	D
85.50	9.68	9.91	P	56.52	11.37	11.89	D
85.63	9.77	10.01	D	66.50	11.37	11.89	D
86.50	9.49	9.69	P	66.54	11.30	11.81	P
86.52	9.77	10.01	D	67.53	11.37	11.89	P
87.49	9.18	9.34	D	69.51	11.47	12.01	D
87.50	9.35	9.53	P	70.52	11.37	11.89	D
87.55	9.23	9.39	D	70.56	11.30	11.81	P
88.57	9.23	9.39	P	76.5	11.28	11.79	P
89.58	8.87	8.98	D	77.51	11.42	11.95	D
90.52	8.64	8.72	P	77.55	11.3 :	11.8 :	P
91.53	8.94	9.06	D	78.51	11.42	11.95	D
92.54	9.17	9.32	P	81.91	11.22	11.71	D
93.55	9.24	9.40	P	82.50	10.8 :	11.2 :	D
94.51	9.43	9.62	P	85.96	8.46	8.52	P
2414995.52	9.55	9.76	P	2415086.93	8.46	8.52	D

TABLE III.—*Continued.*

Julian Day	Magnitude		Obs.	Julian Day	Magnitude		Obs.
	Vis.	Ph.			Vis.	Ph.	
2415087.92	8.46	8.52	D	2415191.66	11.30	11.81	P
89.91	8.66	8.75	D	91.70	11.27	11.77	D
90.93	8.71	8.80	D	92.60	11.37	11.89	D
93.94	8.85	8.96	P	94.65	11.37	11.89	D
5095.94	10.30	10.63	P	94.66	11.39	11.92	P
5100.86	11.14	11.62	D	95.68	11.37	11.89	D
02.81	11.37	11.89	D	96.62	11.37	11.89	P
13.79	11.35	11.87	D	96.64	11.37	11.89	D
29.77	11.37	11.89	D	96.84	11.30	11.81	P
34.75	11.27	11.77	D	97.62	11.32	11.83	D
35.73	9.32	9.49	D	97.62	11.37	11.89	P
36.86	8.68	8.77	D	98.61	11.3 :	11.8 :	P
36.87	8.59	8.67	P	5199.62	11.32	11.83	D
37.74	8.66	8.75	D	5200.64	8.78	8.88	P
38.88	8.82	8.92	D	00.71	8.76	8.86	D
39.85	9.00	9.13	D	01.64	8.45	8.50	D
39.86	9.01	9.14	P	02.62	8.36	8.40	D
41.87	9.87	10.13	P	03.60	8.31	8.35	D
43.87	10.66	11.05	D	04.62	8.31	8.35	D
44.80	10.97	11.41	D	05.60	8.37	8.42	P
45.82	11.37	11.89	D	07.67	8.56	8.82	D
49.87	11.44	11.98	D	09.64	8.56	8.63	P
60.70	11.37	11.89	D	11.62	8.69	8.78	P
60.83	11.23	11.72	P	11.63	8.76	8.86	D
65.78	11.37	11.89	D	12.60	8.62	8.70	P
66.81	11.37	11.89	D	13.64	9.06	9.19	D
68.83	11.35	11.87	P	14.61	9.27	9.44	D
70.68	11.42	11.95	D	15.67	9.53	9.73	D
74.66	11.37	11.89	P	16.64	9.99	10.27	D
75.66	11.30	11.81	P	17.60	10.44	10.79	D
76.79	11.42	11.95	D	17.64	10.46	10.81	P
80.73	11.32	11.83	D	18.67	10.86	11.28	D
81.73	11.32	11.83	D	19.61	11.15	11.63	D
83.61	<10.5 :	<10.9 :	P	22.65	11.37	11.89	D
84.75	11.44	11.98	P	24.65	11.37	11.89	D
85.73	11.34	11.86	P	28.63	11.47	12.01	D
86.62	11.44	11.98	P	29.65	11.37	11.89	P
87.62	11.3 :	11.8 :	P	31.66	11.52	12.07	D
88.64	11.33	11.84	P	32.60	11.44	11.98	D
89.64	11.37	11.89	P	33.63	11.42	11.95	D
90.69	<10.5 :	<10.9 :	P	34.66	11.47	12.01	D
2415190.73	11.32	11.83	D	2415235.62	11.47	12.01	D

Fig. 2 gives a general view of the light changes, the time interval covering one of the double periods, including a "short" and a "long" maximum. The magnitudes are expressed on the visual scale, and the time coördinate is chosen rather short in order to include in one figure the complete cycle of light

changes. As in previous years, the star remained quiet at normal light, 11.34 magnitude, for about three fourths of the time, then rose quickly to maximum at 8.5 magnitude; the greater part of the rise, from 11th to 9th magnitude, occupying nineteen hours. The decline was much slower than the rise, both after long and short maxima. The star was above normal light for twelve days at the short, and nineteen days at the long maxima. The periods of normal light averaged forty and forty-four days after the short and long maxima respectively. The form of the

LIGHT CHANGES OF *SS Cygni*.

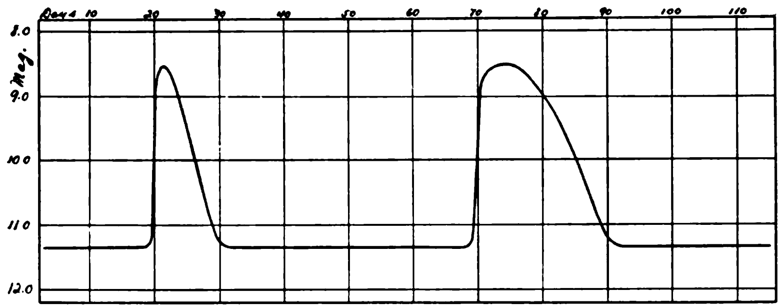


FIG. 2.

light curves was such that the times of maxima were usually uncertain by a considerable fraction of a day, which amounted to a whole day at the long maxima. The rise, however, was so prompt that the time of passing 9.35 magnitude (the mean of the comparison stars *a* and *c*) could usually be fixed within one tenth of a day. In the discussion that follows this time is called T_0.

Table IV gives a résumé of the results for the entire period during which we have had the star under observation. A sufficient explanation of the contents is given in the headings of the columns, except for the number of the epoch in the second column. For maxima No. 3 to 19, inclusive, the long and the short type alternated without a break in the order. For the purpose of discussion, the different types are numbered and considered separately, giving eight short and seven long maxima in the set.

TABLE IV.

RESULTS FROM DECEMBER 1896 TO JULY 1900.

No.	Epoch	Rise began	T_0	Maximum	Above normal	Reached normal	Remained at normal
		J. D.	J. D.		days	J. D.	days
1	(long)	3939	3940	'97, Jan. 20 3945	20	3959	44
2	(short)	4003	4004.5	Mar. 22 4006	13	4015.9	22
3	0 (short)	4038	4039.0	April 25 4040	11	4049.0	30
4	0 (long)	4079	4080.4	June 8.6 4084.6	19	4098.0	46
5	1 (short)	4144	4145.4	Aug. 10.1 4147.1	13	4157.0	37
6	1 (long)	4194	4196.2	Oct. 1.4 4200.4	20	4214.1	44
7	2 (short)	4258	4259.5	Dec. 2 4261	13	4271.5	34
8	2 (long)	4306	4307.2	'98, Jan. 21.4 4311.4	19	4325.4	44
9	3 (short)	4369	4370.0	Mar. 22.6 4371.6	13	4382	45
10	3 (long)	4427.3	4427.8	May 22.2 4432.2	20.1	4447.4	43
11	4 (short)	4490	4491.4	July 21.8 4492.8	11	4501.0	36
12	4 (long)	4537	4538.4	Sept. 9.6 4542.6	19	4556	48
13	5 (short)	4604.0	4605.1	Nov. 13.0 4607.0	11.1	4615.1	45.7
14	5 (long)	4660.8	4661.8	'99, Jan. 10.5 4665.5	18.4	4679.2	41.6
15	6 (short)	4720	4721.6	Mar. 9 4723	11	4731	44
16	6 (long)	4775	4776.8	May 5 4780	20	4796	41
17	7 (short)	4837.0	4838.0	July 3.8 4839.8	14.0	4851	38
18	7 (long)	4889.0	4890.0	Aug. 26.6 4893.6	19	4908	44
19	8 (short)	4952.2	4953.0	Oct. 26.8 4954.8	12.4	4965.0	15
20	anomalous	4980	4987.5	Dec. 2.2 4991.2	19	4999	21
21	(long)	5020	5021	'00, Jan. 7 5027	19	5039	43
22	(long)	5082	5083	Mar. 8 5087	20	5102	33
23	(short)	5135.0	5135.7	Apr. 27 5137	11.0	5146.0	53.5
24	(long)	5199.5	5200.5	July 3.2 5204.2	21.5	5221.0	

It will be noticed that this cycle was preceded by two short maxima in succession, Nos. 2 and 3, and closed by the anomalous maximum No. 20 (which will be considered later) followed by two long maxima in succession. It is possible that this is only half a complete cycle which will be finished when the

SS Cygni 1897–1900.

NORMAL CURVES FROM LONG AND SHORT MAXIMA 1 TO 8.

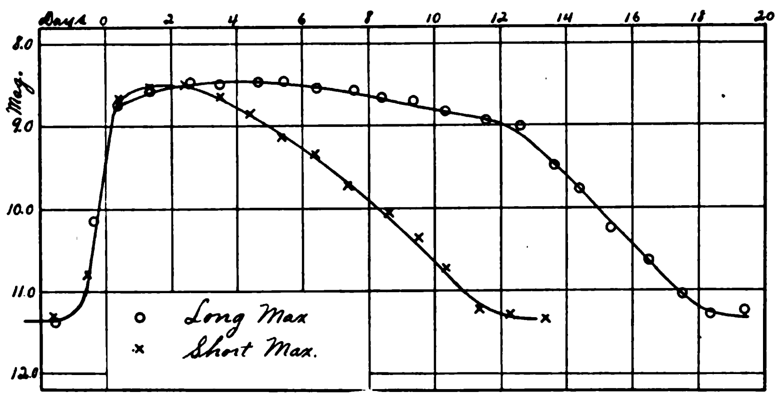


FIG. 3.

present set is ended by a repetition of two successive short maxima like Nos. 2 and 3, but this can be settled only by assiduous observations in the future.

NORMAL CURVES.

Considering maxima Nos. 3 to 19 as forming a complete set, the observations, 619 in number, were used to form normal curves by arranging them in order of the time (T) elapsed from the T_0 of each maximum. Table V, giving the results for the short and long maxima, was formed by taking daily means of the T's and the corresponding magnitudes, which are expressed both on the visual and photometric scales. A graphic representation of these results is given in Fig. 3. In both types the rise begins suddenly and proceeds with the same rapidity. The crest of the wave occurs at 2.0 days after T_0 for the short, and at 5.0 days for the long maxima. The fall from magnitude 9.0 to 11.0 taking place at the same rate, occupies about six days in

each type. The sharp turns in the curve at the beginning and end of maximum are peculiar to this type of variable.

The anomalous maximum of November-December 1899 deserves special attention, being utterly unlike the usual types. The difference appears by comparing the curves in Fig. 3 with that in Fig. 4, taken, by the courtesy of the editor, from the January 1900 *Popular Astronomy*. The reality of the curve in Fig. 4 is attested by the accordant results of the four observers, David Flanery, of Memphis, Tenn., and William E. Sperra, then of Randolph, O., besides the writers.

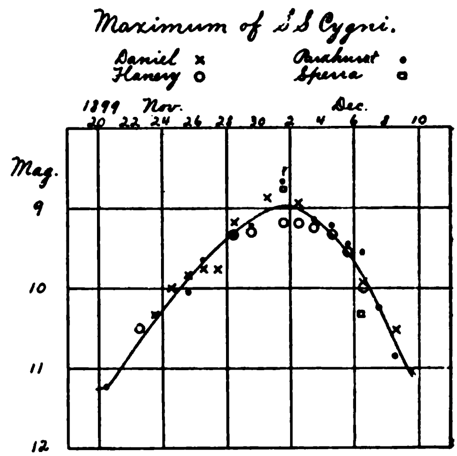


FIG. 4.

The behavior of the star during its periods of normal light is but slightly less important than the maximum curves, and deserves close inspection. In Fig. 2 the normal light is drawn as a uniform horizontal line at magnitude 11.34. As the accuracy of this conclusion has been questioned the following investigation was made. Means were first formed of the magnitude for each period of normal light separately, between maxima Nos. 3 and 20. The results, expressed both in visual and photometric magnitudes, are shown in Table VI, with the number of observations on which each mean depends. The brightest mean is 11.21, the faintest 11.40, the general mean 11.34. The average difference between each quantity and the general mean is 0.05, showing that the several periods of normal light have substantially the same magnitude. A test of the variation during the separate periods is shown in Table VII. For this purpose the magnitudes are grouped in five-day intervals, and the mean of each interval, numbered 1 to 9, is given;

TABLE V.

NORMAL POINTS FROM DAILY MEANS.

No.	Short maxima				Long maxima			
	T	Magnitude		No. obs.	*T*	Magnitude		No. obs.
		Vis.	Pho.			Vis.	Pho.	
1	−2.76	11.28	11.79	3	−2.47	11.38	11.91	3
2	−1.58	11.30	11.81	8	−1.46	11.32	11.83	9
3	−0.57	10.80	11.21	11	−0.36	10.18	10.49	10
4	+0.35	8.67	8.76	9	+0.42	8.77	8.87	10
5	1.33	8.53	8.60	8	1.42	8.59	8.67	12
6	2.38	8.51	8.57	7	2.57	8.48	8.54	8
7	3.49	8.66	8.75	7	3.47	8.51	8.57	10
8	4.42	8.85	8.96	10	4.60	8.48	8.54	7
9	5.30	9.17	9.32	8	5.46	8.46	8.52	5
10	6.38	9.37	9.55	6	6.47	8.57	8.64	6
11	7.39	9.74	9.98	8	7.52	8.59	8.67	10
12	8.61	10.03	10.32	9	8.38	8.66	8.75	5
13	9.53	10.36	10.70	8	9.43	8.70	8.79	9
14	10.30	10.74	11.10	6	10.32	8.83	8.93	4
15	11.27	11.22	11.71	4	11.51	8.95	9.07	8
16	12.27	11.31	11.82	3	12.53	9.01	9.14	8
17	+13.38	11.36	11.88	2	13.60	9.48	9.68	5
18	......	....	....	..	14.43	9.77	10.01	8
19	......	....	....	..	15.38	10.26	10.58	8
20	......	....	....	..	16.48	10.63	11.01	11
21	......	....	....	..	17.50	11.06	11.52	6
22	......	....	....	..	18.27	11.31	11.82	2
23	......	....	....	..	+19.44	11.24	11.74	7
				117				171

TABLE VI.

MAGNITUDES DURING THE SEPARATE PERIODS OF NORMAL LIGHT.

Between maxima	Magnitude		No. of obs.	Between maxima	Magnitude		No. of obs.
	Vis.	Pho.			Vis.	Pho.	
3– 4	11.24	11.74	8	11–12	11.40	11.93	16
4– 5	11.26	11.76	57	12–13	11.40	11.93	20
5– 6	11.32	11.83	58	13–14	11.38	11.91	21
6– 7	11.31	11.82	37	14–15	11.36	11.88	7
7– 8	11.30	11.81	5	15–16	11.36	11.88	5
8– 9	11.40	11.93	15	16–17	11.35	11.87	16
9–10	11.38	11.91	9	17–18	11.25	11.75	18
10–11	11.39	11.92	18	18–19	11.34	11.86	17
				19–20	11.21	11.70	4

the last two columns combining the like-numbered intervals for the three years, and the last line combining all the intervals for each year separately. It may be stated, as the conclusion, that these observations furnish no evidence of a variation in light during a single normal period, or of a difference in the separate periods.

TABLE VII.

PERIODS OF NORMAL LIGHT.

Means of 5-day intervals.

Intervals	1897	1898	1899	Mean Mag.	
				Vis.	Pho.
1	11.26	11.42	11.28	11.32	11.83
2	26	35	31	31	82
3	29	46	29	35	87
4	27	37	22	29	80
5	26	38	35	33	84
6	32	36	30	33	84
7	36	39	35	37	89
8	35	43	34	37	89
9	11.30	11.44	11.37	11.37	11.89
Means	11.30	11.40	11.31	11.34	11.85

ELEMENTS.

It will be evident from an examination of Table IV that neither the maxima nor the times called T_0 follow at regular intervals, yet the inequalities in the periods do not exceed a few days. Considering the short and long maxima separately, a least-square solution made in 1899, when the maxima from No. 3 to 13 were available, gave the elements:

$$\text{No. 1}\begin{cases}\text{For short max., } T_0 = \overset{\text{J. D.}}{4039.0} + 107^d.745\ E + 1^d.095\ E^2 \\ \text{For long max., } T_0 = 4080.4 + 112^d.58\ \ E + 0^d.74\ \ E^2,\end{cases}$$

in which E is the epoch number. In deducing these elements the observed dates were assumed as the zero epochs, and the only unknowns were the coefficients of the first and second powers of E. Using the maxima Nos. 3 to 19, and introducing

a term for the correction to the zero epoch, we deduce the following elements:

$$\text{No. 3}\left\{\begin{array}{l}\text{For short max., } T_0 = \overset{\text{J. D.}}{4033.8} + 113^d.29\,E + 0^d.20\,E^2 \\ \text{For long max., } T_0 = 4080.0 + 114^d.73\,E + 0^d.17\,E^2.\end{array}\right.$$

A comparison of the observed dates with these two sets of elements is given in Tables VIII and IX, in which the first column gives the epoch number; the second and third columns give respectively the observed times, T_0, and the intervals; the fourth and fifth columns give the dates as calculated by Elements No. 1 and the residuals in the sense observed minus computed; the sixth and seventh columns the corresponding quantities for Elements No. 3. The first set of elements are seen to represent the observed times fairly well as far as Epoch 6, after which the

TABLE VIII.

RESULTS FOR SHORT MAXIMA.

E	Observed		Calculated			
			Elements No. 1		Elements No. 3	
	T_0	Int.	T_0	O-C	T_0	O-C
	J. D.	d	J. D.	d	J. D.	d
0	4039.0		4039.0	0.0	4033.8	+ 5.2
		106.4				
1	4145.4		4147.8	− 2.4	4147.3	− 1.9
		114.1				
2	4259.5		4258.9	+ 0.6	4261.2	− 1.7
		110.5				
3	4370.0		4372.1	− 2.1	4375.5	− 5.5
		121.4				
4	4491.4		4487.5	+ 3.9	4490.2	+ 1.2
		113.7				
5	4605.1		4605.1	0.0	4605.3	− 0.2
		116.5				
6	4721.6		4724.9	− 3.3	4720.7	+ 0.9
		116.4				
7	4838.0		4846.9	− 8.9	4836.6	+ 1.4
		115.0				
8	4953.0		4971.0	−18.0	4952.9	+ 0.1
		130				
	5083		5097.4	−14	5069.6	+13
		116				
	5200.5		5226.0	−27	5186.7	+14

TABLE IX.

RESULTS FOR LONG MAXIMA.

E	Observed		Calculated			
			Elements No. 1		Elements No. 3	
	T_0	Int.	T_0	O-C	T_0	O-C
	J. D.	d	J. D.	d	J. D.	d
0	4080.4		4080.4	0.0	4080.0	+ 0.4
		115.8				
1	4196.2		4193.7	+ 2.5	4194.9	+ 1.3
		111.0				
2	4307.2		4308.5	− 1.3	4310.1	− 2.9
		120.6				
3	4427.8		4424.8	+ 3.0	4425.7	+ 2.1
		110.6				
4	4538.4		4542.6	− 4.2	4541.6	− 3.2
		123.4				
5	4661.8		4661.8	0.0	4657.9	+ 3.9
		115.0				
6	4776.8		4782.5	− 5.7	4774.4	+ 2.4
		113.2				
7	4890.0		4904.7	−14.7	4891.2	− 1.2
		131				
	5021		5028.4	− 7	5008.5	+12
		114				
	5135.7		5153.6	−17.9	5126.1	+ 9.6

divergence becomes intolerable. The Elements No 3 represent the maxima of the cycle quite closely, the greatest differences O − C being + 5.2 and − 5.5 for the short maxima. The average difference for the short maxima is $2^d.0$ and for the long maxima $2^d.2$.

At the foot of each table are given two unnumbered epochs to show how the elements will represent the maxima which come after the end of the cycle and the reversal of the order. Bearing in mind that on account of this reversal the maxima are of the opposite kind from the heading of the table, it will be seen that the differences are all positive, that is, the maxima are delayed by about 12 days.

An interesting fact is brought to light by a consideration of the lengths of the periods of normal light following the different maxima. In the set Nos. 3 to 19 the long maxima were followed by normal periods of from 41 to 48 days, averaging 44.

The short maxima were followed by quiet periods of from 30 to 46 days, averaging 40 days. But after the reversal the long maximum No. 22 was followed by a normal period of 33 days, 7 days shorter than any of the above; and the short maximum No. 23 was followed by 53.5 days of normal light, 7.5 days longer than any short maximum in the previous set: so that the reversal is shown not alone by the time of maximum but also by the length of the following period of normal light.

The foregoing facts suggest many interesting questions which cannot be discussed in this paper. In *V. J. S.*, **34**, 316, Dr. Hartwig suggested a theory to account for the variations—a companion revolving in a very eccentric orbit—but such a system would seem to be unstable.

The light curve of *SS Cygni* bears a striking resemblance to that of the "Cluster Type," so interestingly treated by Professor S. I. Bailey in Vol. X, p. 255, of the ASTROPHYSICAL JOURNAL. Indeed, if No. 33 of Professor Bailey's list can be taken as a sample, whose time of rise was found by Professor E. E. Barnard to be only 15 or 20 minutes, the light curve is almost identical in proportions with that for the long maximum of *SS Cygni*.

All the published observations of maximum No. 1, which preceded the two successive short maxima Nos. 2 and 3, are consistent with the same anomalous form as No. 20, which preceded the two successive long maxima. It is hoped that any other observations made in January 1897 may be published or communicated to the writers.

The times of the coming maxima cannot be safely predicted with our present knowledge. Elements No. 3 represent a uniformly increasing period, but it is not unlikely that the increase will be checked or even changed to a decrease. If this is true, the maxima for the remainder of 1900 may occur about October 20 and December 15. It must not be supposed that the presence of decimals of a day in the elements is intended for the purpose of prediction. They are merely to represent the past maxima as closely as possible, and may be of value in comparison with similar elements deduced from future cycles of maxima.

August 1900.

THE AUXILIARY APPARATUS OF THE MILLS SPECTROGRAPH FOR PHOTOGRAPHING THE COMPARISON SPECTRUM.

By W. H. Wright.

In accurate spectroscopic work involving the use of comparison spectra, the design of the apparatus for introducing the comparison is one of fundamental importance, though it is governed by considerations of the greatest simplicity. While the requirements of the case are very generally understood, it may be well for the sake of completeness to mention them here. It is essential: first, that the pencils of rays from the two sources should practically coincide within the spectroscope; and, second, that the two spectra should be observed as nearly simultaneously as possible. The first consideration is always important, while the second becomes equally so when, as in the case of stellar spectrographic work, the exposures are long, and the temperature and position of the spectroscope are continually changing.

The usual practice of observers with stellar spectrographs is to limit the part of the slit devoted to the light of the star by opaque diaphragms, of one form or another. When it is desired to photograph the comparison spectrum, this portion of the slit is covered, the diaphragms are removed, and the comparison light is thrown through the exposed extremities. Precautions are taken to insure the complete illumination of the collimator lens by light from every point of the illuminated portion of the slit. In this manner the first condition is fulfilled, and by distributing the exposures to the comparison spectrum symmetrically in point of time with regard to the middle of the exposure, the second is approximately satisfied. The method has been found very practicable. It has, however, some objectionable features, among which may be mentioned the following: first, the various adjustments usually require considerable time, so that in general it is not expedient to interrupt the star exposure

more than once for the purpose of introducing the comparison; and, second, the mechanism near the slit requires some handling during the operation, and is therefore liable to occasional accidental jarring. Another method, adopted for a time by an eminent observer, was to place the source of comparison light permanently at some distance in front of the slit. This enabled him to use it at frequent intervals during the exposure to the star, but allowed only an incomplete illumination of the collimating lens.

In many cases a totally reflecting prism has been used as a convenience in throwing the artificial light into the collimator; but one of its most valuable properties, that of allowing the collimating lens to be simultaneously filled with light from two different sources, does not seem to have been taken advantage of in the construction of stellar spectrographs. With a view to utilizing this property, the slit mechanism of the Mills spectrograph has been somewhat modified. While formerly the effective length of the slit was limited by opaque diaphragms as mentioned above, this is now done by two prisms so placed as to throw artificial light into the collimator.

As the plan has worked in a most satisfactory manner, it may be well to give a few of the details of the new mechanism, though these have been controlled largely by the construction of the old apparatus. The essential features are shown in plan in the upper part of Plate XX, the lower part giving a sectional view through the collimator and slit. $s\ s'$ is the slit, P, P', are reflecting prisms mounted on sliding carriages c, c'. These carriages are operated by a right and left-handed screw M, by means of which the effective slit may be adjusted to any desired length. L, L', are condensing lenses of 19 mm focus, which form images of the iron electrodes I, I', at i and i'. The angles at i and i' are 49°, and the lines $I\ L$ and $I'\ L'$ make angles of 8° with the slit plates, which therefore do not interfere with the converging pencils from the lenses.

In order to accommodate the change in focal length of the thirty-six-inch objective, due to variation of temperature, the

collimator tube and slit must be moved in the line of collimation. The supports for the electrodes and condensing lenses are therefore attached to the collimator tube instead of the framework of the instrument. The construction of the apparatus allows for all necessary adjustments.

In order to insure the complete illumination of the collimator lens, the image lenses L, L', have, as is usual in such cases, been given a diameter larger than that theoretically required. The actual aperture is 9 mm, while the theoretical aperture is 2 mm. To test the collimation adjustment of the comparison apparatus, a cap having a central aperture of 1 mm is placed over one of the image lenses (and then the other), the corresponding electrode in each case being sparked. If under the circumstances any light passes through the spectroscope and partially illuminates the camera lens, or what amounts to the same thing, forms a spectrum too bright to be due to diffused light from the reflecting prisms, the adjustment is considered sufficiently accurate, and the cap is removed.

Every adjustment of the apparatus is made once for all, and the exposure is given by merely passing the spark. The diaphragms used formerly to limit the effective length of the slit are well adapted to regulating the length of the lines of the comparison spectrum, when this is considered desirable. The apparatus is lightly constructed, the weight being about nine ounces.

A more or less ideal condition in the use of the spectrograph might seem to be one which allowed the exposure to the comparison to continue during the entire interval of the star exposure. The light of the comparison is, however, usually much brighter than the starlight, and there are other practical difficulties in the way of the realization of such a condition. In fact, there is a certain advantage in photographing the comparison at intervals, to which attention has been called by a number of observers. If the several exposures to the comparison are not allowed to overlap, data are furnished for detecting the amount of shifting of the spectrum during the exposure. The exposures

with the Mills spectrograph may very conveniently be given in four sets.[1]

1. The brighter lines on one side of star spectrum.
2. " fainter " " other " " " "
3. " fainter " " first " " " "
4. " brighter " " second " " " "

In determining the times at which these exposures should be given it has been convenient to assume that the position of a line varying as the result of continuous changes of temperature, flexure, etc., in the instrument may be expressed in terms of the first three powers of the time, as follows:

$$x = a + bt + ct^2 + dt^3 \; ; \tag{1}$$

x being a distance measured along the spectrum from some fixed point on the photographic plate, and t being the time. In work of the character considered, the plates are usually rapid and the exposures not above normal, so that to a certain degree of approximation, other things being equal, the photographic effect of light may be considered as proportional to the time of exposure. Upon this assumption the mean position of a line of wave-length λ, exposed from $-\frac{1}{2}T$ to $+\frac{1}{2}T$ (T being the interval of exposure to the star) is

$$x_0 = \frac{1}{T}\int_{-\frac{1}{2}T}^{+\frac{1}{2}T} x\,dt = \frac{1}{T}\int_{-\frac{1}{2}T}^{+\frac{1}{2}T} (a + bt + ct^2 + dt^3)\,dt = a + \frac{c}{12}T^2 . \tag{2}$$

This should coincide with the position resulting from the mean of the four exposures actually given. As there are roughly 50 per cent. more lines in the second and third exposures than in the first and fourth the former have been given weight 3 and the latter weight 2. Assuming a distribution of exposures symmetrical in point of time with regard to the middle of the star exposure, the times may be represented by

$$-\tau_2 , \; -\tau_1 , \; +\tau_1 , \; +\tau_2 .$$

Let the corresponding positions of a line of wave-length λ be

$$x_1 , \; x_2 , \; x_3 , \; x_4 \; ;$$

[1] See CAMPBELL, this JOURNAL, 8, 139.

then

$$x_0 = \frac{1}{10}(2x_1 + 3x_2 + 3x_3 + 2x_4);$$

or, by (1),

$$= a + \frac{c}{5}(3\tau_1^2 + 2\tau_2^2);$$

which, by (2), results in

$$\tau_2^2 = \frac{5}{12}T^2 - \frac{3}{2}\tau_1^2. \tag{3}$$

Either τ_1 or τ_2 may now be assumed, and the other determined by this relation. It will be seen by making $\tau_1 = \tau_2$ that the assumed conditions can be satisfied by two exposures; but since a variation more irregular than that assumed in (1) would be corrected for in a better manner by a greater number and a more uniform distribution, the general practice has been adopted of giving four exposures, assuming $\tau_1 = \frac{1}{8}T$. In case of short exposures, τ_1 is assumed to be zero, and the exposures are given in three sets.

The apparatus was placed on the Mills spectrograph with the approval of Dr. Campbell, to whose suggestions a number of the details are due. It has been in operation for three months, and its performance has been most satisfactory. Among its chief advantages are the following:

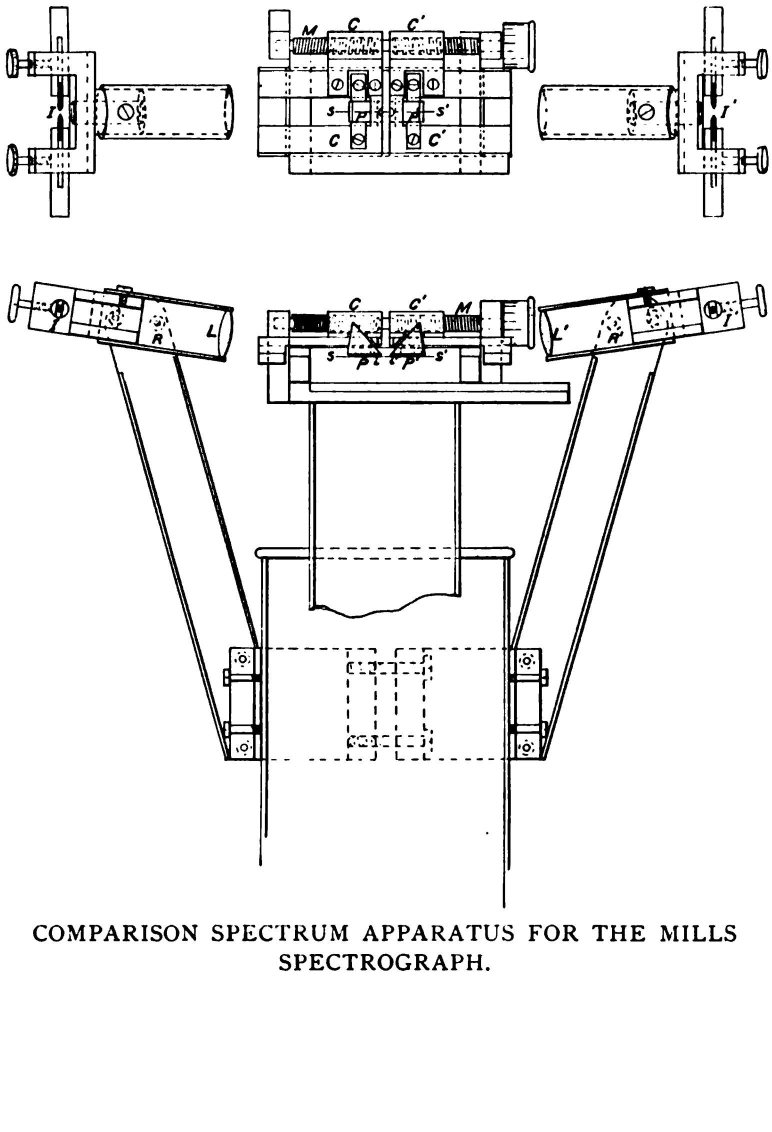
1. It allows the comparison spectrum to be photographed at will, without interrupting the exposure to the star.

2. It is always in adjustment, and therefore effects a saving of time and trouble.

3. The slit remains undisturbed during the entire exposure, and is therefore not liable to accidental displacement.

Lick Observatory, University of California,
September 1900.

PLATE XX.



COMPARISON SPECTRUM APPARATUS FOR THE MILLS SPECTROGRAPH.

"A SUGGESTED EXPLANATION OF THE SOLAR CORONA."

By SIR WILLIAM HUGGINS.

PROFESSOR SCHEINER, in a paper bearing the above title[1] makes the statement:

> . . . . that the opinion seems to have been general that this incandescence (of solid or liquid particles) arises in a manner similar to that of shooting stars and meteors from friction in the outer solar atmosphere (p. 25).

And further on he says:

> The idea that the cause of the incandescence of the meteoric particles in the neighborhood of the Sun is to be found in the direct solar radiation is so obvious that it is surprising that it has not hitherto been expressed in the literature of the subject—at least I have been unable to find anything of the sort (p. 26).

For the sake of historical accuracy it seems to me to be desirable to point out that in my Bakerian Lecture on the corona of the Sun, given before the Royal Society in 1885,[2] the view taken of the corona was inconsistent with the meteoric friction hypothesis, and, indeed, the incandescence of the solid or liquid particles was attributed directly to the "enormous radiation" of the Sun to which they are subjected. I will confine myself to two or three short extracts.

> . . . . These considerations appear to me to be of great weight in support of the view, that though some meteoroid and some cometary matter may fall into the Sun, the corona consists essentially of matter coming from the Sun (p. 124).

> . . . . The corona must, therefore, consist of a fog in which the particles are incandescent, and in which the gaseous matter does not form a continuous atmosphere . . . . A fog, even so extremely attenuated, would probably be fully sufficient to give rise to the corona under the enormous radiation to which it is subjected (p. 122).

[1] This JOURNAL, 12, p. 25.

[2] *Proc. Roy. Socy.*, 1885, p. 108.

The main conclusions at which I had arrived in 1885 were summed up in my Presidential Address of 1891[1] in the following words:

In a discussion in the Bakerian Lecture for 1885, of what we knew up to that time of the Sun's corona, I was led to the conclusion that the corona is essentially a phenomenon similar in the cause of its formation to the tails of comets—namely, that it consists for the most part probably of matter going from the Sun under the action of a force, possibly electrical, which varies as the surface, and can therefore in the case of highly attenuated matter easily master the force of gravity even near the Sun. Though many of the coronal particles may return to the Sun, those which form the long rays or streamers do not return; they separate and soon become too diffused to be any longer visible, and may well go to furnish the matter of the zodiacal light, which otherwise has not received a satisfactory explanation (*loc. cit.* p. 11).

The results of the bolometric examination of the inner corona by Mr. Abbott, under the direction of Mr. Langley, during the recent total eclipse of May last, showing that its light does not contain the predominance of infra-red rays usual in the spectra of hot bodies; and on the other hand the successful photography by Mr. Newall of Savart bands in the coronal light where the Fraunhofer lines were very feeble, have opened questions of interest as to the view we should take of the coronal matter. We await the new information on these points which we may reasonably expect from the long duration of the total eclipse of next year.

LONDON,
September 26, 1900.

[1] *Report Brit. Assoc. Adv. Sci.*, 1891, p. 1.

THE PROBLEM OF THE DAYLIGHT OBSERVATION OF THE CORONA.

By R. W. Wood.

Shortly after the eclipse of May 28 it occurred to me that the strong continuous spectrum of the corona might furnish a means of mapping its form in full sunlight by some method utilizing the light *within* some broad Fraunhofer line of the sky light close to the Sun. I found, however, on looking over the literature on the subject, that this method had been most thoroughly tried by Professor Hale with his spectroheliograph, unfortunately without results. It then occurred to me that possibly a more sensitive method would be to look for traces of polarization within the dark lines.

So far as I know, no one has attempted to devise any method depending on coronal polarization for the detection of the Sun's corona in full daylight. At first sight the method seemed quite hopeful. The sky light close to the Sun was found to be quite free from polarization, when examined with a Savart plate which is capable of showing 1 per cent. of polarized light, while observations which I made with the same instrument at Pinehurst last May convinced me that the coronal polarization may amount to 15 per cent. or even 20 per cent. Through the courtesy of Professor Campbell and the Regents of the University of California, the facilities of the Lick Observatory were placed at my disposal during the past summer for as long a time as I chose to devote to the problem. A further study of the conditions, however, convinced me that the plan was almost hopeless, nevertheless on account of its importance I resolved to make at least a few preliminary experiments. The results were negative as I had expected, but a record of the work may suggest a more hopeful method to some more skillful experimenter.

I had decided to limit myself at the start to a search for traces of polarization in the light of the sky close to the Sun.

Once having accomplished this, the designing of a recording instrument for mapping the corona would doubtless present no great difficulty.

My original plan was to form an image of the sky immediately adjoining the Sun on the slit of a spectroscope in such a way that the plane of polarization of the corona would coincide with the plane of the slit. A Savart plate placed in the eyepiece with a Nicol prism would then show, if properly adjusted, dark bands crossing the spectrum at an angle of 45° with the Fraunhofer lines, provided the light contained 1 per cent. or more, of polarized light. I scarcely hoped to find the bands crossing the bright parts of the spectrum, but thought it possible that they might be detected within some of the broad lines, if the rest of the spectrum were screened off. A fundamental objection to the plan occurred to me, however, before I even commenced experimenting. The polarized light of the corona must be reflected sunlight. The unpolarized may be in part emitted and in part reflected. The polarized portion should then have a spectrum similar to sunlight, *i. e.*, containing the Fraunhofer lines. We should not then expect polarized light corresponding to the wave-lengths of these lines to be present, or in other words we should not expect to find traces of polarization within the dark lines.

There is, however, a factor which may modify this condition. If the reflecting particles have any considerable to-and-fro motion in the line of sight the reflected waves will be altered in length by Doppler's principle, and the change in wave-length in the case of light reflected under certain conditions is double the change effected on emitted light. It thus appears possible that internal motion in the corona may be operative in effacing the Fraunhofer lines. The breadth and haziness of the 1474 coronal line in some of Professor Campbell's photographs indicate the possibility of such internal motion, though certain conditions of pressure and temperature may be all that is necessary to give a line of this appearance. Assuming the absence of the Fraunhofer lines to be due to internal line of sight motion we

might hope for traces of polarization within the dark lines of the sky light.

The few experiments that I made gave negative results, but my time was limited, and I still think it barely possible that with suitable apparatus something might be accomplished.

I was unable to find any data regarding the residual light within the lines of the Sun's spectrum. There must of course be some, for it is hard to conceive the absorption as complete. Added to this light would be the light *emitted* by the coronal particles in virtue of their incandescence. The amount of this may, however, be smaller than would appear at first sight. Assuming internal motion, I see no reason why we should attribute the continuous spectrum to incandescent solid or liquid particles.

Unquestionably matter, as near the Sun as the coronal particles, must be at a high temperature, but I am inclined to think the reflected light would be vastly in excess of the emitted. So far as I know, no data exist regarding the ratio of the reflected and emitted light of a body brought to a state of incandescence through exposure to radiation. Whether laboratory data would have much value or not I do not feel prepared to say, so much would depend on the wave-length of the exciting radiations. In the extreme case of Tyndall's dark heat focus, all the visible light would be emitted. On the other hand a small object placed in the focus of an immense burning glass exposed to sunlight, shines principally by reflected light.

The chief experimental difficulty that I have found is one that was anticipated from the start, namely the polarizing power of the prism. I have been unable to find any dispersing piece that does not polarize. Even a Rowland metal grating gives strongly polarized spectra. In the case of prisms, as we increase the dispersion we increase the polarization by the addition of new surfaces. The spectrum of the Mills spectrograph we found could be almost extinguished by a Nicol prism.

A direct-vision prism seemed to be the best for the work. The one that I used at Pinehurst polarizes only about 5 per cent.

of the transmitted light, and this can be corrected by a plate of glass placed in a plane at right angles to the plane of the prism's face, and inclined at the proper angle. By this device the Savart bands could be made to disappear entirely from the spectrum. Whether there were maxima and minima within the Fraunhofer lines it was impossible to tell on account of the narrowness of the lines. Higher dispersion would have weakened the light too much, besides introducing more polarization than could be conveniently compensated. Possibly a photographic method might show them. If the spectrum were screened off with the exception of a single line, a plate moved at a right angle to the direction of the line might reveal the presence of maxima and minima as "trails" of light and shade. It might even be possible to use a dense photographic negative of the spectrum as a screen and in some way utilize the light inside of all of the dark lines. I fear, however, that very great difficulties would be found in working with such an integrating screen.

In addition to the work with the spectroscope, an attempt was made to detect traces of coronal polarization in the region immediately adjacent to the Sun. If the corona contained 20 per cent. of polarized light and the sky light superposed on it was not more than twenty times as bright as the corona, the Savart plate placed in the eyepiece of a telescope should give a feeble indication of the presence of the corona. The object-glass must receive no direct sunlight, since in this case a large amount of light is sent into the eyepiece from specks and bubbles in the glass.

To secure suitable conditions a small telescope was set up in the shadow of a tall iron smoke stack, which barely hid the disk of the Sun. Not a trace of the Savart bands were to be seen, however. I have been unable to find any consistent data regarding the relative brilliancy of the coronal and sky light. One observer records it, if I remember right, as 1 to 500. My own estimate, based merely on observation, would put it much lower than this, but it is certainly high enough to mask all traces of

polarization, at least in such instruments as are at our disposal at the present time.

One other point occurs to me in connection with the subject. Some observers claim to have detected the Fraunhofer lines in the spectrum of the corona. Usually they are not seen, however. Possibly this may be explained by the polarization of the reflected light. Let us consider the coronal light to be chiefly emitted light, with a small amount of reflected light, as is usually assumed. The reflected light only will exhibit the Fraunhofer lines, and this light is strongly polarized. Now the dispersing piece can act as an analyzer as well as a polarizer. Suppose the slit of the spectroscope to be placed tangentially. The plane of polarization will then be at right angles to the slit, the oblique faces of the prism will consequently transmit these radiations, and the Fraunhofer lines may appear in the spectrum.

If, however, the slit be placed radially, the plane of polarization will be parallel to the slit, and the prism faces will almost completely reflect the polarized light and the dark lines will consequently be absent.

Janssen in 1871, and Stone in 1874, both working with a tangential slit, observed dark lines. Mosely in 1877, and Burton in 1890, with slit tangential saw no distinct continuous spectrum, owing doubtless to too high dispersion.

Other observers, working with a radial slit, found no traces of the lines.

Professor Campbell showed me a photograph of the corona's spectrum which he made at the Indian eclipse, beautifully sharp and clear, but without a trace of a dark line. He worked with a tangential slit.

These cases, which are all that I have found in which the slit's position is recorded, are in accord with the above theory of the absence of the lines. It seems to me that it would be well at the next eclipse to work with a tangential slit provided with a Nicol prism. By setting the Nicol in the proper position the polarized light would be wholly transmitted, while the

unpolarized, or emitted light would be reduced in intensity by one half. This change in the ratio of the intensities might be sufficient to show the dark lines very distinctly. By turning the prism through an angle of 90° the dark lines would vanish. If a grating is used the slit should be radial, since in this case we work with reflected light.

PHYSICAL LABORATORY,
UNIVERSITY OF WISCONSIN.

OBSERVATIONS OF THE TOTAL SOLAR ECLIPSE OF MAY 28, 1900, AT ARGAMASILLA, SPAIN.

By H. Deslandres.

Total eclipses of the Sun, during the few seconds of totality, afford the only known opportunity to study the *corona*, which is the highest and most extensive part of the solar atmosphere, and the *reversing layer*, a region at the base of this atmosphere and of the chromosphere which is so thin that hitherto it has never been possible to observe it in full sunlight, even with the most powerful telescopes.

I planned to study these two important parts of the Sun, giving special attention to phenomena hitherto unknown. I made careful preparations for: first, the determination of the velocity of rotation of the corona by the spectroscopic method, which I was the first to apply for this purpose in 1893; second, (*a*) the examination of the ultra-violet spectrum of the corona, in the second or more refrangible region (from λ 3500 to λ 3000), which is absorbed by ordinary glass, and which I was the first to obtain, though in an incomplete manner, in 1893; (*b*) the examination of the ultra-violet spectrum of the reversing layer in the second region, not hitherto attempted; third, the study of the heat spectrum of the corona (not hitherto attempted) in a region far beyond the red; this study, as will be seen below, is important in connection with subsequent researches on the corona; fourth, the direct photography of the corona with slow plates of very fine grain.

In carrying out this program I enjoyed the aid of seven assistants, one of whom brought with him a chronophotograph kindly loaned by M. Marey.

Rotation of the corona.—For this investigation I used three spectroscopes of high dispersion, a visual spectroscope with grating, and two photographic spectroscopes having two and three flint prisms respectively. The displacements and velocities

were measured by the method of inclined lines, which I devised for the study of the rotation of *Jupiter*, and of *Saturn* with its rings, and which may be used with a small solar image. The visual spectroscope was adjusted for the green coronal line; but this was not seen at first, as it was faint, short, wide, and diffuse. On the east side of the equator, the inclination seemed to correspond to a rotation more rapid than that of the disk.

The two photographic spectroscopes were arranged so that each might receive three solar images upon its slit. I obtained in this way the spectra (from λ 4800 to λ 3700) of six double sections or of twelve sections parallel to the solar equator and equally spaced on the coronal ring. The lines of the chromospheric gases and the continuous spectrum are fairly intense on the negatives; but the coronal lines, which are essential for a study of the rotation, are almost completely lacking, except at two points, where they attain the small height of 3′, and are well adapted for measurement. The faintness of the coronal lines at the period of the Sun-spot minimum has already been pointed out.

Ultra-violet radiation.—I mention first a small spectroscope of Iceland spar and quartz, giving a very bright spectrum, previously employed at Senegal, which was used to obtain the complete ultra-violet spectrum (height 15′) without details.

The most perfect optical parts of Iceland spar and quartz were reserved for two cameras of 0.50 m and 1 m focal length with objective prisms; for while the slit spectroscope gives to better advantage the spectrum of a given point, the objective prism gives the spectra of all points at once.

With these two cameras ten photographs were obtained which give: (1) the entire ultra-violet spectrum of the reversing layer, including the half already known, from λ 4000 to λ 3500, and the half not hitherto recorded, from λ 3500 to λ 3000; (2) the entire ultra-violet spectrum of the upper chromosphere, not hitherto observed by the classic method of Janssen and Lockyer; (3) the entire spectrum of the corona, with two complete rings due to two new coronal radiations.

The above photographs required a long exposure, on account of the faintness of the extreme ultra-violet rays; they therefore could not show the curious and rapid changes in the spectra of the solar and chromospheric crescents.

I supplied this deficiency, thanks to M. Marey, who very kindly loaned me for a few days one of his chronophotographs, with movable film. The apparatus was attached to a train of four objective prisms of crown glass, giving the ultra-violet spectrum from λ 3800 to λ 3500. In two minutes it supplied as many as five hundred successive pictures 2 cm long and 3 cm wide, which clearly show the progress of the phenomenon. One of these photographs shows the complete series of at least twenty-four ultra-violet hydrogen lines, which is so remarkable on account of the mathematical regularity of the spacing.

Mention may also be made of a camera provided with an objective grating and adjusted for the green coronal line; this gave only chromospheric arcs, with no trace of the coronal ring, thus supplying additional proof of the faintness of the lines of the coronal gases.

Heat radiation.—I have already pointed out the special importance of the heat rays for the study of the corona. For the blue light of the sky, which hides from us the stars and the corona, is rich in very refrangible rays, but must be poor in rays of small refrangibility. An eye sensitive to only the extreme infra-red rays would see the stars in full daylight, and I have announced that the detection of the corona without an eclipse depends upon the photography of images with the heat rays. But it is desirable to find whether the corona strongly emits these rays.

I prepared special apparatus comprising a large silvered mirror of short focus for projecting the solar image, a slit spectroscope with crown prism, and a very sensitive Melloni pile with a Deprez-d'Arsonval galvanometer. The pile received only infra-red heat from the region near λ 13000.

On the day of the eclipse, before, during, and after totality, measures were made of the heat radiated from the center of the

Moon, and from points in the sky at distances of 3′, 6′, and 20′ from the Sun's limb. The heat at the center of the Moon decreased progressively until it reached zero at totality; and at this moment points in the corona 3′ and 6′ from the Sun's limb gave deviations of 5 and 3 scale divisions. These same points, without an eclipse and for the same altitude of the Sun in a very transparent sky, have at times given deviations of 11 and 7 divisions. The heat of the corona was thus half of the total radiant heat.[1] This simple experiment clearly indicates the possibility of obtaining the corona without an eclipse by means of the heat rays.

Direct photography of the corona.—This was accomplished only with small telescopes of 1.10 m, 0.40 m, and 0.30 m focal length, as the Meudon Observatory could not place at my disposal the large objectives of its collection. But the negatives were made on slow plates of fine grain and can be greatly enlarged. On some of these plates the equatorial streamers extend two diameters from the Sun.

The numerous instruments described above were carried by an old 8-inch equatorial and by two equatorial mountings, one of wood and one of metal, constructed especially for the eclipse. The last mentioned, of metal, is at once light and stiff, and includes certain special features. It carries large tables, readily accessible from all sides, on which instruments can be arranged as easily as upon a laboratory table. This design may be recommended for astrophysical investigations.

In closing, I may add that the duration of totality was found to be five seconds less than the calculated duration.

[1] With the ordinary luminous rays the ratio between the light of the corona and that of other points in the sky, under ordinary conditions, is very different. In the green-yellow, the intrinsic light of the corona is at most the fortieth part of the light of the sky under ordinary conditions, according to recent photometric measures. Hence arises the almost absolute impossibility of obtaining the corona without an eclipse with the visible rays.

Reviews

AN ATLAS OF REPRESENTATIVE STELLAR SPECTRA.[1]

THE prominent part played by the Tulse Hill Observatory in the development of astrophysical research renders the appearance of its first volume of *Publications* an event of unusual importance. It is difficult for those who are acquainted through experience with the spectroscopic progress of only one or two decades, to realize the state of the science at a time when the light of a star had never been subjected to searching analysis. At present it seems a simple matter to attach a spectrograph to a powerful telescope and photograph the spectrum of a star. But the ability to do this was not achieved at a single stroke: it is the result of a long series of experiments dating back to the first work of Sir William Huggins at the Tulse Hill Observatory in 1862.

At that period, when object-glasses were smaller, telescope mountings less stable, and driving-clocks less efficient than those of the present day, the task of observing the spectrum of a star must indeed have appeared a formidable one. It is true that Fraunhofer, at the beginning of the century, had examined starlight with a prism placed over the object-glass of a telescope, and had even been able to detect differences among stellar spectra which, though not understood by him, have since proved to be of fundamental importance. But the plan deliberately chosen by Sir William Huggins was one much more difficult of realization. Recognizing the fact that the objective prism would not permit the use of a comparison spectrum, which is indispensable for the measurement of wave-lengths in stellar spectra, he resolved to attach an ordinary laboratory spectroscope to the eye-end of his 8-inch telescope. The star image must then be made to fall on the slit, where it must be accurately maintained as long as the spectrum remained under observation. Furthermore, as the image of a star is practically a point, its spectrum is linear, and must be broadened

[1] *Publications of Sir William Huggins' Observatory*, Vol. I. By Sir William and Lady Huggins. London: William Wesley & Son, 1899.

with a cylindrical lens, in order to render its character apparent. In spite of all difficulties, the observation was successfully made, in collaboration with Dr. W. Allen Miller, and in a short time it was possible to announce the presence in the stars of many well-known terrestrial elements.

It would be a pleasant task to follow through the first chapter of the volume as it recounts the many successes of the Tulse Hill Observatory's pioneer days. Here, for the first time, in August 1864, a nebula was found to give the spectrum of a glowing gas. Only two years later spectroscopic observations of the star which suddenly appeared in *Corona Borealis* revealed the presence of both dark and bright lines, some of the latter due to incandescent hydrogen. Then in turn came the first attempt to measure the motion of a star in the line of sight, the detection of hydrocarbon bands in the spectra of comets, and various researches in solar spectroscopy, particularly in the observation of the chromosphere and prominences without an eclipse. In 1876 a most important advance was made when the first photograph was secured of the spectrum of *α Lyrae*. This and other similar photographs included the invisible ultra-violet region, and for the first time brought to light the remarkable rhythmical spectrum of hydrogen. They also afforded material for a preliminary discussion of the evolutional order of the stars. A short time later the method of photographic registration was extended to the spectrum of the great nebula in *Orion*, and to the spectra of comets.

To the general reader this historical chapter, recounting the experiences of an amateur whose privilege it was to make discovery after discovery in an untried and almost unknown field of research, is likely to prove the most fascinating portion of a book which should do much to arouse interest in the New Astronomy.

Dr. Huggins' marriage, in 1875, secured for him (to use his own words) "an able and enthusiastic assistant," who has never since ceased to take a most active part in the observational and other work of the Observatory. Toward the preparation of the present volume for the press, Lady Huggins has contributed in large measure. In addition to the strictly scientific side of her collaboration, she has effectively decorated many pages with drawings of the Observatory and its surroundings, copies of old engravings, etc., inserted, for the most part, as chapter headings and initial letters. With these embellishments, the beautifully printed and bound book, with its broad margins and

attractive letterpress, affords an appropriate setting for its important contents.

The opening chapter, as already stated, contains a history of the Observatory and its work. Chapter II is a list of published papers. The next three chapters describe the instruments with which the photographs reproduced in the plates were made. Chapter VI, which is perhaps the most important section of the whole work, is devoted to a discussion of the evolutional order of the stars and the interpretation of stellar spectra. The valuable plate of historical spectra is described in chapter VII, and the text concludes with chapter VIII, in which the stellar spectra on the plates are given a preliminary discussion. These excellent half-tone plates, twelve in number, seem to bring out the details of the original negatives in an admirable manner. The authors have shown good judgment in using direct photographic reproductions, untouched by the engraver's tool. The slight loss of detail, which is inevitable in such cases, is more than compensated for by the perfect reliability of the illustrations, which never show more than the photographs themselves. The false lines, which seem to be unavoidable in enlargements of stellar spectra that have been widened vertically, are not seriously in evidence, and in most cases they can be easily eliminated on account of their fortuitous distribution, particularly since the spectra on a plate are generally so related that common lines can be traced from star to star. The wave-length scale accompanying most of the spectra will make the photographs far more useful than they would otherwise be.

The principal new contributions to stellar spectroscopy contained in the present volume are the photographs of the ultra-violet spectra of various types of stars, and the discussion of stellar evolution based upon them. These photographs have been taken with an 18-inch reflecting telescope, used in conjunction with a spectrograph containing two Iceland spar prisms.[1] Their importance will be recognized when it is remembered that they constitute practically our only source of information regarding the extreme ultra-violet region of stellar spectra. It is indeed rather surprising that in the years which have elapsed since the first photographs of stellar spectra were obtained in this very region, practically no advances have been made except at the Tulse Hill Observatory. The comparative scarcity of quartz or of

[1] For Sir William's original description of this spectrograph, see this JOURNAL, 1, 359, 1895.

Iceland spar prisms and well-mounted reflecting telescopes may perhaps account for this, but it is evident that a most promising field of investigation lies open at this end of the spectrum. Sir William and Lady Huggins have apparently not made extensive measurements of their negatives. A solar spectrum taken with the same instrument is employed as a standard of comparison for both wave-lengths and relative intensity. Two scales of enlargement are used for the illustrations. The smaller, 4¾ diameters, permits the entire range of the spectrum, from λ 4570 to λ 3300, to be included on a quarto page. The larger, 15 diameters, is used for the ultra-violet region only.

In entering upon a discussion of stellar evolution the authors, while premising that the great changes in stellar spectra from one type to another are due to loss of energy through radiation, lay stress upon the spectral differences which may result from the increasing force of gravity in the reversing region. They indeed think it possible that some of the spectral changes observed in stars whose temperature is rising as the result of condensation, may be due primarily to increasing density and in much less degree to higher temperature. The important question whether the diversity of stellar spectra may arise from original differences of chemical constitution is answered in the negative, after an interesting and convincing argument. Helium is very conspicuous in some stars, but it may be doubted whether it is wholly absent from those in whose spectra its lines do not appear. Our knowledge of the presence of helium in the Sun is due solely to the possibility of observing the bright line spectrum of the chromosphere. The remarkable variation in the intensity of the hydrogen and calcium lines in different stars is another case in point. But the strongest evidence is afforded by the gradual change in spectrum from star to star, and the possibility of forming unbroken series beginning and terminating in widely different types. This fact, taken together with the well-known difference between the spectra of the components of double stars, which may be assumed to originate from the same nebula, seems to amount to a demonstration that original differences of chemical constitution play no important part in determining the character of stellar spectra, unless such exceptional cases as that of the Wolf-Rayet stars must be accounted for in this way.

Passing now to the question of stellar classification, Sir William and Lady Huggins retain the commonly accepted view that the white stars represent the earliest stage of development. They select *Bellatrix* as

typical of the youngest stars, partly because of the fact that their photographs of the *Trapezium* stars in the Great Nebula of *Orion* show a similar spectrum. The order of succession of stars from *Bellatrix* through the solar stage and on through Vogel's class III*a* is easily traced. (Stars of Vogel's class III*b* and Wolf-Rayet stars are not considered in the present discussion.) The authors wisely refrain from introducing a new system of nomenclature for the various spectral types.

The extent of the ultra-violet spectrum has generally been considered a fair criterion of a star's effective temperature. As the extreme ultra-violet is most conspicuous in the spectra of the white stars, they have been held to represent not only the youngest, but also the hottest stage. After pointing out that Lane's law, according to which a gaseous mass must rise in temperature as it contracts in cooling, would seem to indicate that the highest temperatures must be sought in some class other than the first, the authors seek to test the question by the results of observation. Excepting *Sirius*, on account of its large parallax, most of the brightest stars in both hemispheres are at or near the solar stage. The authors conclude that, for the same distance and brightness, the effective temperature of a solar star must be much higher than that of a white star, on account of the far greater number of dark lines in the spectrum of the former, and their effect in cutting down the light. If, however, the solar star were of larger diameter than the white star, the equal effective brightness of the former might conceivably be due to the integrated effect of a greater number of less intense rays.

The investigations of Vogel, Langley, and others have shown that the general absorption of the solar atmosphere is much more pronounced for short waves than for long ones. The effect, then, of the increasing general absorption which may accompany the passage from the first to the second class would be to cut off the extreme ultra-violet spectrum. If the views of Sir William and Lady Huggins are correct, however, the position of maximum intensity in the spectrum advances toward the ultra-violet during this period of transition, attains its limit when the star is in some such condition as that of the Sun, and then retreats toward the less refrangible region as the temperature falls.

The difficulty of testing this conclusion arises not alone from the unequal effect of the increasing general absorption, but also from the presence of such a multitude of dark lines as the solar spectrum contains, not to speak of instrumental troubles and those that may be

due to our own atmosphere. It is evident that spaces between Fraunhofer lines must be selected for comparison with the broad regions of continuous spectrum in the white stars. The authors consider that the evidence of their photographs supports the new view. Just beyond the head of the hydrogen series the spectra of stars of the first class seem to fall off greatly in brightness, while the spectra of solar stars, though they do not extend so far into the ultra-violet, nevertheless appear to be stronger in this region when equally intense in the blue. Reproductions are given of several photographs made for the purposes of this comparison. Some of these seem to show the effect very clearly, notably in the case of *Capella* as compared with *Procyon* (Fig. 1). The original negatives, however, must be far more satisfactory than any form of reproduction for a delicate comparison of this kind.

Measures of the heat radiation of *Arcturus* and *Vega*, made by Professor E. F. Nichols at the Yerkes Observatory in 1898 and 1900, indicate that we receive from the former star (mag. 0.03) about twice as much heat as from the latter (mag. 0.19). As the two stars differ so little to the eye in brightness, this seems to indicate that the proportion of long heat-waves is greater in the spectrum of *Arcturus*. If the accuracy of the heat measures could be relied upon, if the important law $\lambda_{max.} \times T = \text{const.}$ could be considered to hold for both stars, and if the effect of increasing absorption were not most marked in the shorter radiations of the solar star, it might be fair to conclude that the maximum in *Arcturus* is displaced toward the red, and consequently that its effective temperature is lower than that of *Vega* — a result opposed to that reached by Sir William and Lady Huggins. So far as the reliability of the heat measures is concerned, it may be said, in spite of the minuteness of the observed deflections (about 0.3 mm for *Vega* and 0.6 mm for *Arcturus*), that a repetition of the measures of *Arcturus*, made in 1900, agrees remarkably well with the earlier results. Unfortunately *Vega* could not be reobserved this year. Again, while Paschen's law, which applies to the "black body," is not rigorously true for either star, it is at least safe to say that the maximum moves toward the red with falling temperature. The question of absorption is more doubtful. As the authors have pointed out, the marked effects of general absorption first show themselves far out in the ultra-violet, and advance toward the red as the temperature declines. So long as they are practically confined to the ultra-violet, however, they have no

bearing on the present case. The line absorption is also probably greater in the more refrangible than in the lower spectrum, though as yet we know nothing of the infra-red region of stellar spectra. As the photographs of stellar spectra upon which the authors base their opinion were taken with almost the only instruments in existence that may be considered suitable for the purposes of such a comparison, great weight must attach to their conclusions, even though they differ from commonly accepted views. Further measurements of heat radiation, and photometric observations in the visible spectrum, should throw some light on the question.

If space permitted, much more might be said of this interesting volume. The experiments on the changes in the calcium spectrum produced by varying the density of the vapor, and their bearing on both solar and stellar problems, will not be overlooked by astrophysicists. The extensive series of observations, both visual and photographic, of the spectrum of the *Andromeda* Nebula are of special importance in connection with Scheiner's recent work. The spectra of the *Trapezium* stars, and the excellent examples of the spectra of double stars, also deserve more than a passing reference. The same is true of the numerous spectra on the plates, which are of great service in tracing the course of evolution from star to star. Enough has been said, however, to indicate that the work should be in the library of every spectroscopist. As a means of arousing interest in astrophysical research, it should also be found in collections of books intended for general readers.

G. E. H.

Publicationen des Astrophysikalischen Observatoriums zu Potsdam. Photographische Himmelskarte. Band I. 1899.

THIS volume of over five hundred pages, which are of a somewhat larger size than those of the regular series of Potsdam publications, represents the first contribution to the great catalogue of stellar positions which forms the first part of the immense international undertaking known as the *Carte du Ciel* or Astrographic Chart. It may not be superfluous to allude briefly to the general scope and progress of the enterprise before proceeding to the specific volume in hand, inasmuch as the *Bulletin du Comité international permanent* does not appear to be very widely circulated.

Since the initial conference in 1887, chiefly organized through the efforts of the late Admiral Mouchez, subsequent meetings of the committee have been held in Paris in 1889, 1891, 1896, and 1900, which have been attended by numerous other interested astronomers upon invitation of the committee. A number of valuable memoirs have been published in the *Bulletin* of the committee, dealing with modes of obtaining, measuring, and reducing the plates, and much progress has been made in placing this branch of astrometry upon as firm a basis as any department of the subject. The two principal parts of the undertaking are (1) the production of the catalogue of the positions of all stars to the eleventh magnitude from measures upon the photographic plates and (2) the production of a photographic chart of the entire sky, upon a scale of 1 mm to 1′, or about two and one third inches to the degree. As the assignment of the zones to the various coöperating observatories has not been published heretofore in the ASTROPHYSICAL JOURNAL, the following list is given, as modified at the meeting of the committee in July:

Zone of Declination		Observatory	Zone of Declination		Observatory
+90° to	+65°	Greenwich	+ 4° to	− 2°	Algiers
64	55	Rome	− 3	− 9	San Fernando
54	47	Catania	−10	−16	Tacubaya
46	40	Helsingfors	−17	−23	Montevideo
39	32	Potsdam	−24	−31	Cordoba
31	25	Oxford	−32	−40	Undetermined
24	18	Paris	−41	−51	Cape of Good Hope
17	11	Bordeaux	−52	−64	Sydney
+10	+ 5	Toulouse	−65	−90	Melbourne

The photographic telescope of the Brothers Henry, of the Paris Observatory, was taken as the model, and accordingly the optical power of the different instruments is closely the same. The aperture is 34 cm and the focal length 343 cm, while the attached visually corrected guiding telescope has the smaller aperture of 23 cm, but the same focal length. There is considerable variety in the form of mounting of the telescopes. The plates are 16 cm square, and upon each, before exposure, a photographic impression is taken of the standard *réseau*, made by Gautier, which contains 26 numbered horizontal lines and an equal number of vertical lines, thus dividing the whole area of the plate into 676 equal squares of 5 mm side. The space within the *réseau*, 13 cm square, therefore contains 4.7 square degrees. For the purposes of the catalogue each star not fainter than the eleventh magnitude

will be twice photographed, the exposures, of about five minutes duration, to be so arranged that the star will once be near the center of the plate. The number of plates required from each of the eighteen observatories averages 1200. It is evident that the work of obtaining these plates, after the problem of the standard instrumental outfit and procedure had been settled, was slight as compared with the enormous task of measuring and reducing the plates, of determining accurately the magnitude of the stars, of comparing the results with other catalogues, and finally of publishing the completed work. In view of the great differences in the financial status of the different institutions, as well as in the amount of other work in their regular programs, it has been necessary to allow wide latitude to the participating observatories in most matters subsequent to the procurement of the plates. In general the reports at the recent conference indicate that the work has progressed well, two thirds of the plates for the catalogue having been already taken (nine of the observatories have completed their assignment), while nearly one fourth of the required number of plates has been measured. The work of making the chart plates, which will require exposures of half an hour or more, is naturally in a much less advanced state, although heliogravure reproductions of them have begun to appear from the Paris Observatory and from some others.

The sub-title of the volume under review is: 20627 *Scheinbare rechtwinklige Coordinaten von Sternen bis zur elften Grösse nebst genäherten Oertern für 1900.0. Bearbeitet von J. Scheiner.* It includes the measurements of fifty-seven of the 1232 plates to be obtained at Potsdam in its zone from 31° to 40° of north declination, expressed in terms of rectangular coördinates in units of the *réseau* interval, together with estimated magnitudes, the magnitudes and number in the Bonn *Durchmusterung* of stars occurring therein, and the approximate right ascensions (to nearest second) and declinations (to tenths of minutes of arc) for 1900.0 of all the stars.

The immensity of the whole undertaking appears when we note that at this rate some twenty more volumes of this size will be required to contain the corresponding results for the remainder of the Potsdam plates. If it should later be decided to convert these rectangular coördinates into accurate mean right ascensions and declinations for a given epoch, by the application of the necessary corrections for the scale and orientation of the plate, for refraction, aberration, precession, etc., then still another series of large volumes will be required.

The reasons are given why this was not undertaken by the Potsdam Observatory, as it will be on the part of certain of the coöperating institutions. A staff of five or six additional computers would be required aside from the present required services of two assistants, two computers, and the supervision of Professor Scheiner; but such increase would seriously limit the work of the institution in its principal field, astrophysics, and the production of a star catalogue is not at all within the normal scope of the Observatory. Aside from this, however, in the present state of astronomy the meridian-circle positions of those stars on a plate which had been included in the *Astronomische Gesellschaft* catalogues, and upon which the reductions to right ascension and declination would have to depend, are not nearly adequately accurate in comparison to the measures on the plate; hence the superiority of the latter would be of no advantage until some future re-observations and re-reductions of these meridian positions shall much increase their precision.

A description is given of the photographic refractor, and of the routine of obtaining the photographs. The measuring machine is also described and the procedure of measuring the plates. It appears that when the measurer dictates the micrometer readings to a recorder (which was the regular practice at Potsdam) somewhat over thirty stars can be measured per hour on the average.

The accuracy of the measure in the volume is discussed in a section of the introduction. Two settings in each coördinate were made upon each star image and upon each side of the *réseau* square. From a comparison of these the probable errors of the mean of the settings is deduced for the two observers at the measuring machine, Dr. A. Schwassman and Miss Alice Everett, and is found to be (mean for the two observers) $\pm 0\overset{r}{.}07$ in R. A. and $\pm 0\overset{r}{.}06$ in Dec. The probable error of the rectangular coördinates is best obtained from a comparison of the positions of stars occurring upon two different plates. Thus three pairs of plates, having in common respectively 13, 24 and 150 stars yielded these probable errors: $\pm 0\overset{r}{.}14$ (R. A.) and $\pm 0\overset{r}{.}13$ (Dec.); $\pm 0\overset{r}{.}15$ and $\pm 0\overset{r}{.}18$; $\pm 0\overset{r}{.}19$ and $\pm 0\overset{r}{.}17$. Professor Scheiner believes himself justified in adopting the simple mean of these, $\pm 0\overset{r}{.}16$ and $\pm 0\overset{r}{.}16$, as representing the measure of accuracy of the rectangular coördinates in the volume. The personal errors of setting of the two observers received attention, but were not as accurately determined as was desired.

The question of the magnitudes of the stars in the catalogue is obviously a difficult one, involving the still undiscovered law of the relation of exposure time to photographic impression. Overlooking Pickering's previous researches on the subject, the committee had originally innocently supposed that the increase in intensity of the star image would be directly proportional to the time, and that therefore only from ninety seconds to two minutes of exposure would be required for stars of the eleventh magnitude, inasmuch as the stars of magnitude 9.0 and 9.5 in the *B. D.* were readily obtained in about thirty seconds. After considerable discussion and experimentation with absorbing screens of wire network, it became apparent that about five minutes was the necessary exposure time for the eleventh magnitude stars, and this has been pretty generally employed by the participators.

No general legislation was adopted governing the determination of the magnitudes fainter than the ninth, except that they should be brought into relation with some existing system of magnitudes. For this that of the *B. D.* would naturally suggest itself, in spite of the uncertainty of its estimates of the 9.5 and tenth magnitudes. In the work at Potsdam, where the plates are only taken on clear nights and when the region photographed is near the zenith, the assumption has been made that the faintest measurable objects are of magnitude eleven; and the magnitudes between this point and the ninth (taken from the *B. D.*) are directly interpolated. The magnitudes were not determined by measurement of the diameters of the star disks, but by simple estimation to quarters of a magnitude; the accordance of these estimates is about the same as that of the ordinary eye estimates of the *B. D.* It will be interesting to know in how far the measures of the star disks in progress at some of the observatories yield more accurate results. A table in the introduction, obtained from a comparison of all stars of the *B. D.* found on the plates, gives the corrections necessary to reduce the photographic magnitudes to those of the *B. D.*, arranged for each plate according to magnitude. In some cases these corrections run as high as a magnitude, but for the most part are much less.

An interesting discussion is given of the comparison of the numbers of stars in equal areas of the plates and of the *B. D.* The least number of stars on a plate is 40, of which 37 are contained in the *B. D.*; the greatest number is 1830, of which 156 are found in the *B. D.*, so that the ratio of numbers of stars varies from 1.1 to 11.7. It appears

from a comparison of the plates of sparsely occupied regions of the sky with regions thickly occupied that the ratio of the "star density" between the Potsdam catalogue and the *B. D.* increases nearly proportionally to the star density itself. This discussion has elsewhere been published and need not be further considered here.

An important feature of the work has been the careful comparison with the places of the *B. D.* All stars of the *B. D.* not found on the plates, or differing more than 4^s in R. A. or $3'$ in Declination, were especially looked for and in most cases found as very faint objects. In case of objects then outstanding Professor Deichmüller, of Bonn, undertook the careful examination of the original MS. records of the B. D., the results of which are given in detail at the end of the list of measures on each plate.

In the catalogue the plates so far measured are taken up in succession, in order of R. A. within a given zone of 1° Dec., but as this volume contains plates whose centers were on the parallels +32°, 33°, 34°, 35°, 36° and 37°, the sequence in R. A. is often interrupted. At the head of each plate's list are given: the date and time of the exposure; the temperature, barometric pressure, and focal setting of the instrument; the steadiness and transparency of the air; the R. A. and Dec. of the origin of the coördinates for that plate (center of the *reséau*); the position and magnitude of the guiding star employed; and the name of the observer at the telescope and at the measuring machine.

A summary at the end of the volume shows the areas covered by the different plates, with the pages on which they are to be found, which would prove to be very necessary in the practical use of the work.

The question of the immediate utility of the volume here considered, in its present form, is perhaps an open one. The approximate R. A. and Dec. of all the stars included make it of the greatest value as extending the Bonn *Durchmusterung* to stars of the eleventh magnitude, and reduction tables are given which make it possible to convert the rectangular coördinates into R. A. and Dec. with an approximation perhaps sufficient for most comparison stars for comet observations. But the convenient arrangement of the *B. D.* is wanting, and when the zone here considered is completed it will be necessary to consult a somewhat voluminous index in order to find the volume which includes the plate covering the area in which a star is sought. Until the zone

is completed a reference to the work may require the examination of all the volumes that have appeared at the time.

Hence, and especially in view of the insufficient accuracy of the meridian circle positions of the fainter stars, the full value of the accurate measures of these volumes is not likely to be available for many years.

E. B. F.

Strahlung und Temperatur der Sonne. Von J. SCHEINER. Leipzig: Englemann, 1899.

IN its convenient compass of one hundred octavo pages this interesting essay treats of the various radiations received from the Sun, and of its temperature. The investigation of the radiations is quantitative rather than qualitative, and theoretical rather than experimental. No consideration is here given to the nature of the radiations as revealed by the spectroscope, and no extended descriptions of actinometers or other instruments for measuring the radiation are included. The book contains neither illustrations nor diagrams, and no unnecessary array of formulæ, although there is no avoidance of those essential to the subject. More than one half of the volume is devoted to the thermal radiations from the Sun, while the luminous, chemically-active, and electro-dynamical radiations can be treated in about eight pages. The first section briefly considers the absorption by the Earth's atmosphere, and an appendix of fifteen pages deals with the diameter of the Sun.

The most valuable part of the work is the discussion of the temperature of the Sun in the light of the recent important theoretical and experimental researches on the law of radiation of the black body by Lummer and Pringsheim, W. Wien, Paschen, and others, many of which have appeared in the pages of this JOURNAL. In his usual luminous style the author examines the validity of the laws of radiation of Newton, of Dulong and Petit, of Stefan, and of others, and shows that Stefan's fourth-power law is the best founded both on theory and experience, so that its use seems fully justified in the extrapolations necessary in application to the Sun.

The formula employed for obtaining the effective temperature of the Sun, the meaning of which term is carefully explained, is

$$x = 273 \cdot \sqrt[4]{\frac{2.48}{\sin^2 \frac{\phi}{2}} \cdot \frac{s}{h_1}}$$

where ϕ is the angular diameter of the Sun, s is the solar constant, h_1 is the amount of radiation from a black body at 100° to another at 0°, and the factor 2.48 is $\left(\frac{373}{273}\right)^4 - 1$. Adopting 4.0 gram-calories per square centimeter per minute as the most probable value of the solar constant, based upon the most reliable determinations, and using Kurlbaum's value of $h_1 = 1.056$, the effective temperature of the Sun is found to be 7010°, absolute. Should the smaller value of $s = 3.75$ be preferred, the temperature will be 6900°.

The apparently hopelessly irreconcilable determinations of this temperature by various early observers, whose values ranged through millions of degrees Centigrade, are now shown to be surprisingly accordant when reduced by Stefan's law. Those so reducible are

Pouillet	5600°
Secchi	5400
Violle	6200
Soret	5500
Langley	6000

To these may be added the measures of Rosetti, reduced by his own empirical law and yielding a result of 10,000°; and of Paschen, who employed empirical corrections to Stefan's law, and obtained 5000°. The reviewer has excluded the value of 6200°C. given for the measures of Wilson and Gray, and reduced by them according to Stefan's law, as Professor Scheiner evidently had not seen their article in full as published in *Philosophical Transactions* for 1894. In this they adopt Ångström's larger estimate of the terrestrial absorption, and increase their number from 6200° to 7400°C. In a later communication to this JOURNAL (August 1899) they give reasons for increasing the latter value by 30 per cent., stating that an experimental investigation is in progress for clearing up this point.

It is evident that the principal outstanding uncertainty at present is due to the atmospheric absorption, and the value of 7000° adopted above allows most liberally therefor, whence its larger value. In order to obtain the true effective temperature of the photosphere, however, the absorption in the solar atmosphere must be taken into account. Considerable space is therefore given by Professor Scheiner to a statement of the work by different observers on this subject. He adopts the rounded figure 1.5 as the amount by which the solar radiation would be increased if its atmosphere were removed; so that the solar constant

would thus be increased 50 per cent., rising to 6.0 gram-calories, and the effective temperature of the photosphere would become 7760° Abs. It would seem to the reviewer safe to adopt the value of 1.7, which has been actually found for thermal radiations, in place of the factor 1.5, but this does not much affect the result, yielding almost exactly 8000°, or 7730°C. It thus appears, as is at once seen from the formula, that even a considerable change in the solar constant will produce but little effect on the final temperature, since s is under the radical.

Quite as interesting as this section is the succeeding one, on indirect methods of determining the solar temperature. Here the reader who has not had time to follow the researches of Wien, Lummer and Pringsheim, and Paschen, will find a clear statement of their results and their bearing upon this and other related problems of radiation.

Further sections deal with secular and periodic variations in the solar temperature, the former of course leading to a brief presentation of Helmholtz's contraction theory, and the latter to an allusion to the studies on the effects of Sun-spots on terrestrial meteorology.

The appendix treats, in a somewhat less satisfactory manner, of the unsatisfactory question of the solar diameter. Professor Scheiner adopts as most probable the diameter of $31' \ 59\overset{\prime\prime}{.}26 \pm 0\overset{\prime\prime}{.}10$ obtained by Auwers from a full discussion of the numerous determinations of the solar diameter made on the occasion of the last transit of Venus.

Professor Scheiner's essay is especially to be commended to the attention of teachers, who are likely to find its perusal profitable to a degree quite disproportionate to its size, and who can then supply or correct the omissions or misstatements in regard to the solar temperature which occur in the chapters on the Sun in most of our text-books of astronomy.

E. B. F.

Observations of Variable Stars by Argelander, Schönfeld, and Schmidt. Annals of the Astronomical Observatory of Harvard College, Vol. XXXIII, pp. 29–134.

In this volume Professor Pickering has given a careful reduction and discussion of a large part of the observations of long period variables made by these distinguished astronomers, using photometric magnitudes of the comparison stars, thus insuring a uniform system and furnishing a basis for comparison with later work.

The observations by Argelander include those published by him in Vol. VII of the Bonn *Beobachtungen*, and in addition about 4000 unpublished comparisons made in 1869–1871. The value of one "grade," expressed in photometric magnitudes, was found to be 0.14, and seems to be independent of the magnitudes of the comparison stars or of the intervals covered. Following a table giving the designation, position, and magnitudes of the comparison stars for each of sixteen variables, comes a list of the individual observations, giving the Julian and calendar dates, the adopted magnitude, and the residuals from the comparisons with different stars.

The observations by Schönfeld are given in a similar form. They relate to thirty-two variables of long period, and were made between 1853 and 1859. The value of one "grade" is 0 092 of a magnitude. The individual results are given both in grades and photometric magnitudes.

The observations made by Schmidt were copied from his manuscript at the Potsdam Observatory, and that part published which relates to thirteen variables of long period, mostly naked-eye stars. "Aided by the favorable climate of Athens, he was enabled to observe stars night after night, thus securing a continuity of measures such as can be obtained at few other observatories." Unfortunately the value of the work is lessened by Schmidt's failure to leave on record the data for identifying the comparison stars used; out of eighty-two relating to the thirteen variables, only thirty-four could be identified, and some of these are still uncertain. The relative brightness of the comparison stars was determined from Schmidt's observations, and the series adjusted to the photometric scale when possible. About 7000 individual observations, thus reduced, are published, made between 1845 and 1879.

J. A. P.

THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOL. XII DECEMBER, 1900 NO. 5

The ASTROPHYSICAL JOURNAL is published monthly except in February and August. Annual subscription, $4.00; foreign, 18 shillings. *Wm. Wesley & Son, 28 Essex Street, Strand, London,* are sole foreign agents and to them all European subscriptions should be addressed. All papers for publication and correspondence relating to contributions and exchanges should be addressed to *George E. Hale, Yerkes Observatory, Williams Bay, Wisconsin, U. S. A.* All correspondence relating to subscriptions and advertisements should be addressed to *The University of Chicago Press, Chicago, Ill.* All remittances should be made payable to the order of the *University of Chicago.*

[Entered at the Post Office at Chicago, Ill., as second-class mail matter.]

PLATE XXI

LUNAR CRATER THEOPHILUS AND SURROUNDING REGION

PHOTOGRAPHED WITH 40-INCH VISUAL TELESCOPE AND COLOR-SCREEN BY G. W. RITCHEY

THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME XII DECEMBER, 1900 NUMBER 5

SPECTROSCOPIC RESULTS OBTAINED AT THE SOLAR ECLIPSE OF MAY 28, 1900.

By EDWIN B. FROST.

THE participation of an expedition from the Yerkes Observatory in observing the eclipse was for some months doubtful. On account of the lack of funds for the purpose, it seemed in the preceding winter that it would be impossible to equip and send out a party from the Observatory. In the early spring, however, the chances of financial assistance had improved so that preparations began to be made in the first weeks of April.

In the original plan for the spectroscopic observations it was intended that the principal instrument should be a slit spectrograph, on account of the desirability of securing a metallic comparison spectrum adjacent to the eclipse spectrum, and because of the possibility of bringing a slit spectroscope into perfect adjustment by observations on the Sun previous to the day of the eclipse. As attention was chiefly to be given to the flash spectrum, the plan was considered of selecting for the work a station separate from the rest of the party and near the boundary of the shadow, where the phenomena of the flash at second and third contacts would proceed slowly as compared with the

conditions on the central line of totality. This separation of the party would make necessary an increased amount of apparatus, however, particularly a telescope mounting or another coelostat, and it soon became evident that this could not be procured in the time remaining. As the work of fitting out the instruments for the expedition advanced in the shops of the Observatory, under the efficient supervision of Mr. Ritchey, it further became clear that it would not be possible to construct a suitable mounting for the slit spectrograph, hitherto employed in connection with the 40-inch refractor for stellar work, in the interval remaining before it would be necessary to despatch a freight car with the equipment of the whole expedition. Accordingly, at the end of April, the writer submitted to the Director a plan substituting several objective-prism and objective-grating spectroscopes for the slit spectrograph, and this plan was adopted. These slitless spectroscopes offer decided advantages in their simplicity of construction and mounting, and moreover give the spectrum of a considerable portion of the Sun's limb instead of the small section included within the slit. Furthermore, successful results are much less dependent upon exactly the right instant of exposure than is the case with instruments provided with slits. The fortnight remaining before the necessary shipment of the freight car was fully occupied with the selection and preparation of the prisms, gratings, and objectives, and the supervision of the construction by the carpenters of the wooden mountings for these instruments.

GENERAL ARRANGEMENTS.

A plane silvered mirror of 15 inches aperture had been ordered from Mr. O. L. Petitdidier, and was to be attached to the coelostat mounting which also carried a 12-inch plane mirror furnishing the beam for Professor Barnard's 6-inch long-focus lens. A second silvered mirror of 14 inches aperture, kindly loaned by Mr. Petitdidier, received the beam from the 15-inch coelostat mirror and deflected it northward horizontally at a height of about three feet from the ground. Thus the danger of interference between the 62-foot square tube for the

coronal pictures and the spectroscopic instruments was entirely avoided.

Four square posts about 7×7 inches and 4 feet high were planted at the corners of a rectangle 6 feet long by 3 feet wide so that the beam should pass between the two pairs of posts 3 feet apart. Crosspieces were nailed to the posts so that the instruments could be set up in a plane making an angle of 38° with the horizontal, the west end being the elevated one. The position angles of second and third contact were calculated for our station by Professor Flint, using the determination of latitude and longitude just made by the United States Coast and Geodetic Survey, as 68° 34′ and 264° 16′ from the north point, or 130° 27′ and 326° 10′ from the vertex, differing slightly from the computation previously made by the writer with the coördinates of Wadesboro taken from a map. Inasmuch as these points of contact were 164° apart, the direction of the edges of the prisms or rulings of the grating could not be tangential to the point of contact unless the whole plane of support of the spectroscopes was rotated through 16° between second and third contacts. As this would have greatly jeopardized the stability of the wooden mounting, the writer early decided to make the mounting rigid and let the plane of the instruments make an angle of 8° with the point of each contact.

Inasmuch as a nearly circular beam of light of about 100 square inches section could thus be obtained, it was evidently possible to employ a number of spectroscopes, and the essential parts of six such instruments were taken by the writer for the purpose. Two of these were not used at the eclipse on account of the crowding of the various other spectroscopes into the beam, and on account of the lack of time for their satisfactory adjustment after our arrival at Wadesboro on May 17.

SPECTROSCOPIC OUTFIT.

The following instruments were employed for obtaining the spectrum of the chromosphere and corona:

1. A train of three large prisms intended for the new spectrograph for determining stellar motions in the line of sight now in

the process of construction. These prisms are of unusually white flint glass, and have for the ray λ 4227, for which they were set at minimum, an index $n = 1.6418$. Their height is 2.25 inches (57 mm), and their faces increase in size, being respectively 117 mm, 127, and 135 mm long. The angles of the prisms are 66° 1′, and the total deviation for λ 4227 was 182° 30′. The mean path of the rays in the glass was 206 mm (8 inches), and the theoretical resolving power of the train for λ 4227 was consequently about 107,000.

The prisms were set at minimum deviation for λ 4227 on account of the blue coronal line at λ 4231 which it was hoped could be photographed during totality. No attention was given to the extreme violet region, as it was known that other parties (particularly that from Johns Hopkins University) would be especially well equipped for work in that region, and similarly for the green portion of the spectrum, near the chief coronal line at λ 5303, which was to receive particular attention from the observers from Princeton.

The prisms were mounted in a wooden box 19 × 13 inches in size and 3 inches high, provided with two apertures, one rectangular, 2⅛ inches high and 2½ inches wide, to receive a portion of the beam from the coelostat, and the other circular, of 3½ inches diameter, to receive the lens end of the camera tube. The camera tube, objective and plate-holder were taken from the solar spectroscope of the 40-inch refractor. The objective has an aperture of 3¼ inches, and a focal length of 42 inches, and is corrected for the photographic rays. The plate-holder is movable in a vertical direction so that several exposures may be made on the same plate. The length of spectrum admitted to the plate by this plate-holder is only 75 mm (3 inches), which was unfortunate, as a fairly good focus might have been obtained from the lens over a longer extent of spectrum.

The focal setting of the camera was determined by photographs of star trails at the Yerkes Observatory, and a series of solar spectra of very good definition were obtained at Wadesboro by the use of a collimator of the same size as the camera

lens and the slit of the solar spectroscope. Probably the best method of focusing a prismatic camera is by photographing the spectra of bright stars, as Sir Norman Lockyer has done, but it was not feasible in this case on account of the fixed azimuth of the mounting of the spectroscopes; there were no stars sufficiently bright at the same declination as that of the Sun at the date of the eclipse.

A 3-inch tube of forty inches length was placed in front of the prism box in the path of the beam from the coelostat for the purpose of excluding extraneous light. These tubes and the prism box were firmly attached to a stout board 4 feet in length which was fastened to the crosspieces from the four posts, which formed the basis of the support of all the spectroscopes. The exposures of this prismatic camera were made with a bulb shutter.

2. The instrument second in importance was a small concave grating of 150 cm (59.1 inches) radius, with a surface 44 mm wide and 21 mm high ruled with 14,438 lines to the inch. It was used as a direct grating spectroscope without slit or lenses. Since the object to be observed, the Sun's limb at second and third contacts, was at an "infinite" distance, the focal length of the grating was one half its value with the usual laboratory mounting, or 75 cm. To be in focus for its whole extent the photographic plate should be bent to a radius of one fourth the radius of curvature of the grating, or 37.5 cm. As this was quite impracticable, on account of the danger of breaking the plate as well as from lack of time to construct a proper device for the purpose, a plane plate 4 × 5 in size was used. A simple light-tight box was constructed, of about 6 inches height, 30 inches length, and 18 inches width. The grating was placed in one corner, opposite the aperture of 2 × 2½ inches, and diagonally opposite the grating the plate-holder was held in grooves. Cardboard diaphragms at suitable points within the box protected the plate from stray light. A small brass plate held in place by gravity served as a shutter, and the exposure could be made by drawing a cord. The grating was set in the position perpendicular to

the diffracted beam, to which the plate was also perpendicular. The spectrum of the first order was used, and light of about wave-length λ 4600 fell at the center of the plate.

3. For the visual observation of the flash in order to determine the proper time for making the exposures of the other spectroscopes, a small plane objective-grating was employed. The ruled surface was $2\frac{1}{2} \times 2$ inches, with 14,438 lines per inch. The spectrum of the second order, in the yellow region, was used for the observations. The objective was of 2 inches aperture, and 20 inches focal length. The mounting consisted simply of a square wooden tube, with the grating attached to the prolongation of one of the sides of the tube. The eyepiece gave a power of about 20.

4. A large plane grating, with a ruled surface of five inches and 20,000 lines to the inch, was employed (in the first order) in the hope of photographing the red portion of the flash spectra. The camera lens was a visually corrected objective from the solar spectroscope, of $3\frac{1}{4}$ inches aperture and 42 inches focus, and was mounted in a wooden tube, with the grating set up on the prolongation of one of its sides. The iris shutter was operated by hand by the writer, while observing at the eyepiece of the visual objective-grating. The photographic "Erythro" plates were kindly given by the International Color Photo Company, of Chicago. These have been successfully used at the Yerkes Observatory for photographing the red end of stellar spectra. In order to cut out the violet of the second order a red glass screen had to be inserted in the tube. It was unfortunately quite thick, and this, with the necessarily short exposure, is responsible for the failure of these plates to give results of value. Four exposures were made, of about 5 and 7 seconds at the time of second and third contacts, of 55 seconds during totality, and of $\frac{1}{2}$ second immediately after totality. The last plate faintly shows a few bright and dark lines, and one of the exposures to the flash has a faint streak of spectrum, but the short exposure time, for which the sensitiveness of the plates could hardly be expected to be sufficient, permitted no traces to be impressed on the other plates.

It is to be regretted that another prismatic camera, having as objective a small photographic doublet of 7 inches focus, with a very transparent prism of 60° angle, was not employed at the eclipse for photographing the coronal rings over a long extent of spectrum. On account of its rapidity this camera might perhaps have yielded results for the green coronal line which was not obtained with the more powerful apparatus of some of the other parties at Wadesboro. As the other instruments kept the two observers sufficiently occupied, and as there was no available time in which to mount and adjust this spectroscope until the morning of the eclipse, it seemed best not to attempt to use it.

It is a pleasure to record the indebtedness of our party, and particularly of the writer, to G. S. Isham, M.D., of Chicago, who spent the week preceding the eclipse with us, and took part in the preparations with great vigor, and supplemented his own scientific and mechanical skill by supplying the means for employing additional carpenters. He sent to Wadesboro the large tent which covered the spectroscopic outfit, into which the beam from the coelostat was reflected.

EXPOSURES AND VISUAL OBSERVATIONS.

The exposures with the prism-train and the concave grating were made by Dr. Isham, while the writer observed visually to give the signal for exposures at second and third contacts, and operated the objective-grating for the red end of the spectrum. Although it had not been possible for us to rehearse our parts until the evening before the eclipse, we were fortunate enough to carry out our program of exposures without mishap. Every fifth second of time, beginning 60 seconds before the computed instant of second contact, was called out to us by Professor A. S. Flint, who also observed the times of contact with a 3-inch equatorial mounted near by.

The visual observations of the flash spectrum, or spectrum of the reversing layer at the instant of second and third contacts, did not correspond to the writer's expectations of the appearance

of those phenomena. On looking into the eyepiece about a minute before the predicted time of second contact, the dark Fraunhofer lines were appearing, and were quite sharply defined 45 seconds before that contact, as the solar cusp rapidly narrowed down and gave the equivalent of a narrow slit. The bright helium line D_3 appeared as a bright crescent, rendered irregular by several prominences, some ten seconds before totality, and was followed by a succession of other lines, until perhaps 15 or 20 were visible in the rather small field of the eyepiece, when the signal was given to make the exposures for the first flash. The expected reversal of all the dark lines visible in the field was not observed, and the writer cannot believe that the phenomenon took place in the brilliant and striking manner that has been recorded by other observers, in particular by Professor Young, at other eclipses. The experience of other observers of this eclipse seems to be similar to the writer's.

After changing the plate-holder of the objective-grating for the red end of the spectrum, and beginning with it an exposure on the coronal spectrum, there was an opportunity for the naked-eye observation of the corona. The drawing made from photographs with Professor Barnard's smaller cameras, reproduced as Plate I in this volume of this JOURNAL, represented very well the impression received by Dr. Isham and the writer. A brief glance into the visual spectroscope at about the middle of totality did not disclose any coronal rings, although if the eye had been kept at the eyepiece the D_3 line would probably have been visible as a partial ring during a considerable part of totality. The region of the principal coronal line at λ 5303 was not included in the field of view. The plate-holders had been changed in preparation for the second flash after about 75 seconds of the computed 92 seconds of the totality had elapsed, and the writer's eye was placed in position at the visual spectroscope. Shortly after the call of the eightieth second, to the observer's surprise, the chromospheric lines, or crescents, began to appear, and the signal for exposure was given at what was

probably about six or seven seconds before the count for 92. These exposures appear from the plates to have been a trifle late. That third contact occurred several seconds earlier than had been anticipated was also noted by Professor Flint and by others of our party.

The display of the bright lines of the reversing layer was visually no more brilliant than at the first flash, and they were quickly effaced by the streaks of continuous spectrum which appeared as totality ended. The observer's attention now had to be given to changing plate-holders and making a final exposure, about ten seconds after totality, for the combination spectrum of the meniscus of photosphere (dark lines), and the lower chromosphere at the cusp (bright lines). For convenience this is called the cusp spectrum.

GENERAL FEATURES OF THE PLATES.

Except for the red-sensitive plates already mentioned, Cramer's Crown 4×5 plates were used. They were backed with the caramel mixture employed by Professor Barnard for the large coronal plates. They were developed by the writer, with the assistance of Mr. Ellerman, soon after our return to the Yerkes Observatory. Aside from the four plates exposed to the red end of the spectrum, on which prolonged development failed to bring out images of sufficient intensity to be of value, the photographs may be regarded as satisfactory. The focus of both prisms and grating spectroscopes would probably have been somewhat sharper if it had been possible to adjust them by stellar spectra. There is in case of the stronger bright lines on most of the plates a curious tendency to shade away from sharpness on the side toward red to fuzziness on the side toward violet. That this is not a result of imperfect focusing appears from the fact that it occurred with both prisms and grating, and operated only in the direction of dispersion, and seems to affect the bright lines, but not the dark lines. It is most marked on the first flash with the prism-train, and least so on the first flash with the grating. It is not unlike the hypothetical appearance

depicted by Sir Norman Lockyer on p. 126 of his *Recent and Coming Eclipses* (1900), to illustrate the possible effect of different distributions of concentric layers of vapors above the photosphere. It cannot be thus explained, however, as that would require the haziness to change from the side toward violet to the side toward red between the first and second flashes. The effect of this haziness toward violet upon the measures of the plates taken at third contact is described later. We may now examine the plates in some detail.

Spectrum of the solar cusp just before and after totality.—These two plates were taken with the prism-train, the first at the call of 15 seconds before second contact, and the second at 10 seconds after third contact, with exposures of about one half second. The spectra of the first flash and of the corona were also included on the same plate with the first of the cusp spectra. A corner of the plate was unfortunately broken off in the dark room, as it was being removed from the plate-holder; it was also necessary to cut the plate during development, in order that the development of the weak coronal plate could be pushed further than that of the other two strong impressions on the plate. The appearance of the plate was thus injured so that a reproduction of it is not given. The measurements of the plate were not seriously affected, however, the two parts being separately measured and reduced. A reproduction of the plate of the cusp after totality, enlarged three times, was given in the July number of this JOURNAL (Plate IX, Fig. 2 of this volume).

These plates show many interesting features. The continuous spectrum on the first has a width of 4 mm, the Sun's diameter being 10 mm, while on the second plate the width of the continuous band is 5 mm. This indicated that the first, exposed at the call of 15 seconds before the completed time of beginning of totality, was actually taken at an instant nearer totality than the second, which was exposed at the estimate of 10 seconds after the plate taken at third contact. This confirms the observations made by others that the contacts occurred some seconds in advance of the computed times.

The continuous spectrum is strong on these plates, and a slightly shorter exposure, say of ¼ second, might perhaps have been better. The continuous spectrum is strongest along the center of the spectrum, diminishing slightly toward the edges, which are, however, rather sharper than might have been expected. At about position-angle 90° there is a very strong break lengthwise in the continuous spectrum, of a width of 0.2mm, on the first plate. This is presumably produced by a lunar crater of considerable height and of about forty-five miles diameter. The stronger bright lines extend across this gap, indicating that their level was high enough not to be obstructed by the lunar obstacle. The writer has not taken pains to identify this crater. Oddly enough, a number of the dark lines show marked distortion where they resume beyond this gap. On the second cusp spectrum there is also a conspicuous horizontal gap in the spectrum, but the dark lines as well as the bright can be seen to cross it, indicating that the Moon moved enough during the exposure to uncover that portion of the chromosphere, reversing layer and photosphere.

The first plate covers the region of spectrum from λ 4050 to λ 4430; the second that from λ 4025 to λ 4380; the difference is due to the change of 32′ in the incidence of the light, first from the east limb and then from the west limb of the Sun, so that the images are shifted 10 mm on the second plate. All the stronger lines on Rowland's map are shown as dark arcs, in many cases terminating in bright tips at the edge of the continuous spectrum. It is obviously a matter of the highest importance to determine what lines are thus reversed, for upon this turns the question of the existence of a thin stratum of vapors at the base of the chromosphere, called the reversing layer, by the absorptions of which the dark Fraunhofer lines are produced.

It is undeniable that the first impression produced upon the examination of the plates is that there are many marked differences between the bright line and dark line spectrum, and this impression, shared by Professor Hale and the writer, was stated

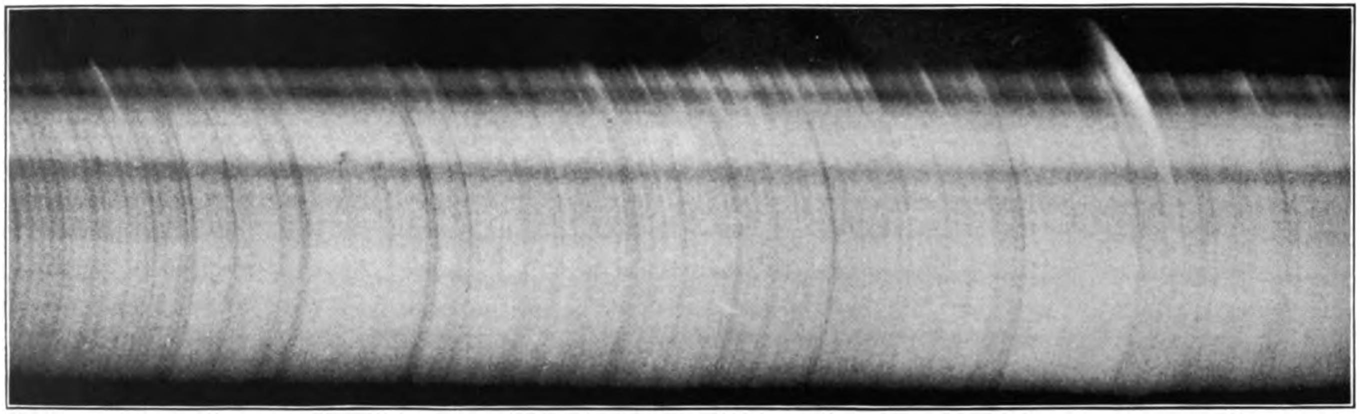
in the Director's report on the observations at the eclipse (p. 86 of this volume of this JOURNAL). The bright lines most conspicuous on account of their intensity and breadth are not the strongest dark lines; a few of the finer bright lines also extend across the whole band of continuous spectrum and do not seem to merge into any dark line. But a close examination, and still better, the measurements detailed below, show that the case is rather exceptional when a strong dark line does not terminate in a bright one. The most conspicuous bright lines in the region of spectrum here covered are the hydrogen lines $H\gamma$ and $H\delta$, the strontium lines at $\lambda 4077.9$ and 4215.7, the calcium line at $\lambda 4226.9$, the line at $\lambda 4177.7$ (perhaps due to iron), a line of uncertain origin at $\lambda 4233.3$, the scandium line at $\lambda 4320.9$, and the chromium line at 4351.9. These have all been long known in the ordinary chromospheric spectrum, and were included in Professor Young's list of lines observed in 1872. Hence it was to be expected that these lines would be conspicuous in the eclipse photographs.

An examination of Plate XXII, which is enlarged eight times from a portion of the original plate of Cusp II, will show quite clearly that very few dark lines can be found, even among the great number in the large group from $\lambda 4285$ to $\lambda 4315$, which do not terminate in a bright tip. This is the essential point in the inquiry as to the existence of the reversing layer. We shall return to it in the discussion of the other plates and of the identification of the lines by their wave-lengths.

Many other phenomena of a highly complex nature are indicated upon these plates taken before and after totality. We are evidently dealing with a superposition of spectra. The bright lines which extend across the whole width of the continuous spectrum appear in some instances to be of different curvature than the dark lines. In some cases the dark lines extend into the bright lines with the same arrowhead effect that is often seen with the prominence spectroscope; in other instances the dark lines merge insensibly into the bright ones.

It is of interest to examine these plates for any uniform

PLATE XXII



PORTION OF SPECTRUM TAKEN TEN SECONDS AFTER TOTALITY

EIGHT-FOLD ENLARGEMENT

relative displacement of the bright lines with respect to their dark counterparts. On the first plate there are many instances in which the bright lines fall on the violet side of the dark lines, that is, on the convex side, but there are several exceptions to this. On the second plate, taken after third contact, many of the bright lines also appear to lie toward the violet of the dark lines, here on the concave side, but also with numerous exceptions. The displacement, where evident, would seldom exceed 0.1 tenth-meter in amount. For studying this point, a slit spectrograph, which avoids the disturbing effect of the curvature of the lines, would seem to the writer more suitable, especially if a metallic spectrum with numerous lines is simultaneously recorded on the plate. In view of the inconstancy of this effect of displacement on the plates here described, it does not seem advisable to base any theoretical considerations upon it.

In the case of the very large bright $H\gamma$ line we have an effect similar to a double reversal; for about the central half of the length of the arc the dark line appears, running out in each direction into a point, from a width at the middle of the arc of about one third of the width of the bright arc.

FLASH SPECTRA AT SECOND AND THIRD CONTACTS.

1. *Plates taken with the prism-train.*—These two plates cover the same range as the corresponding cusp plates. The first records no continuous spectrum, and hence no dark lines; the bright lines merely show a thickening at the parallel along which the contact occurred. Possibly the exposure was made a trifle too late. The second plate, at any rate, which received quite a band (1.5 mm wide) of continuous spectrum, shows many more lines. The exposures were intended to be of two seconds each. Dr. Isham's impression was that the exposure at the first flash was perhaps slightly prolonged beyond the two seconds. Eighty bright lines are given in the tables below as measured on the first plate, and 265 on the second. The second plate, enlarged three times, was reproduced in the July number of the ASTROPHYSICAL JOURNAL (Plate IX, Fig. 1, of this volume). The

streak of continuous spectrum on that plate represents an arc of about 17°. At about position angle 263° the continuous spectrum was interrupted, presumably by a lunar crater.

Just beyond the continuous spectrum, at about position angle 255°, there is a very marked distortion of the bright lines, which may be seen on the reproduction (opposite p. 85). It averages about 0.3 tenth-meter, corresponding to a velocity of recession of about 20 km per second.

Dark lines are very inconspicuous on this plate. This note was made during the measurement of the ten bright lines at the extreme end of the plate toward violet: "All seem to be at the violet edges of dark lines." Between λ 4081 and λ 4086 "numerous dark lines" were noted. Measures were made on five dark lines, as follows:

	Fine	Fine	Fine	? Fine	Quite strong
	λ 4143.8	4150.2	4159.1	4159.6	4168.5
Rowland	4143.57 *Fe* 4 4143.66 2	4149.92 2	4158.96 *Fe* 5	4159.35 5	4168.03 2 4168.13 *Ni* 2 4168.78 2

These lines are not conspicuous in the solar spectrum. They evidently originate at a very low level. The roughly uniform difference of wave-length from Rowland's value is a numerical confirmation of the above statement that the bright lines lie at the violet edges of the dark lines.

The solar prominence at position angle 217° is faintly shown on these plates; on the grating plates it is conspicuous, and the other larger prominences at the date are also seen.

2. *Plates taken with concave grating.*—The total range of spectrum included on these plates is from about λ 3700 to λ 5200, but owing to the necessity of using a flat plate the focus is sufficiently good for satisfactory measurement only from λ 4200 to λ 4900, the lines in which region are included in a subsequent table. The H and K lines are very strong and broad, and about twenty lines, chiefly of the hydrogen series, may be seen beyond K toward the violet, terminating with $H\pi$.

The exposures were intended to be of two seconds each, but it was recorded immediately after totality that the first was

PLATE XXIII

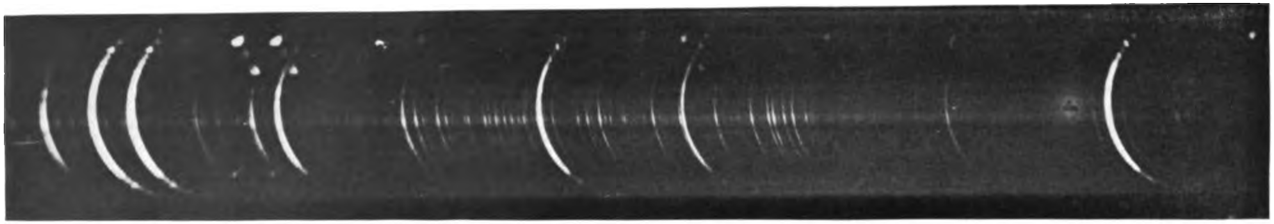


Fig. 1.— Flash at Second Contact

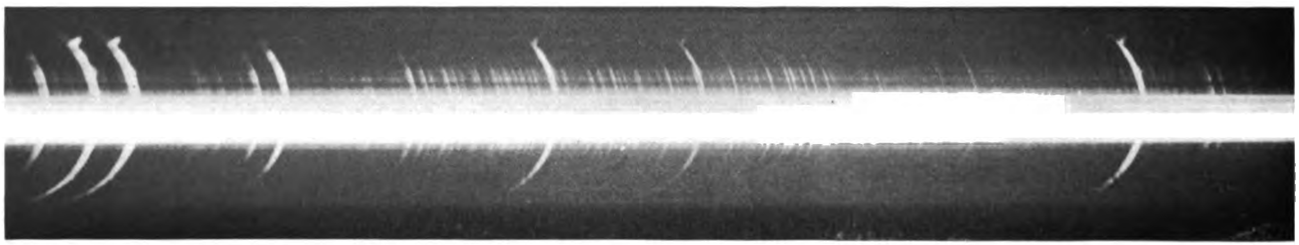


Fig. 2.— Flash at Third Contact

SPECTRA PHOTOGRAPHED WITH CONCAVE GRATING

perhaps underexposed. As will be seen from the reproduction (enlarged 3.4 times), Plate XXIII, Fig. 1, the first plate only received a very slight streak of light, if any, from the photosphere. (In the parts in best focus this band can be almost entirely, if not wholly, resolved into lines.) The second plate (Fig. 2) shows a band indicating that a meniscus of about 25° of photosphere affected the plate before the end of the exposure. A few dark lines appear at the ends of the plate, but not in the central part. Both plates exhibit a broad band of continuous spectrum, slightly greater than the Sun's diameter, which is doubtless due to the inner corona. This band contains certain horizontal streaks of greater intensity, which seem to correspond exactly to those shown on the plate of the corona, of which a figure is given on page 349.

We may obtain an inference as to the height of the strata producing the bright arcs from the measurement of the angular extent of the arcs. The lengths of some of the more conspicuous arcs have accordingly been roughly measured, and are collected in the following table, together with the approximate elevations of the strata deduced from the arcs of the flash spectra. In calculating these values the Sun's semidiameter was taken as 946″.6, and that of the Moon, augmented, as 968″.9.

APPROXIMATE LENGTHS OF CERTAIN BRIGHT ARCS.

Plate	*He* 4471	*H*γ 4340	*Sc* 4321	*Cr* 4274	*Cr* 4254	*Fe* pair 4250	*Y*? 4247	? 4233	*Ca* 4226	*Sr* 4215	*H*δ 4102	*Sr* 4078
Prisms—												
Cusp I		80°						60°	55°	60°	80°	75°
Cusp II		90	55	55		60	65	70	65	70	90	85
Flash I					40	10	45	35	45	60	85	65
Flash II		100	50	45	50	30	55	45	55	65	100	95
Grating—												
Flash I	100	95	45	35	45		55	45	50	60	80	50
Flash II	105	110	45	45	50		55	45	55	70	100	75
Approximate height	8″	8″	3″	2″	3″	< ½″	2″	2″	2″	3″	7″	4″

The arcs for the greater number of lines are not longer than those of the iron pair at λ4250, whence we may safely infer that

the elevation of the strata producing most of the bright lines is less than 1″ above the solar photosphere.

MEASUREMENT OF THE PLATES.

The negatives were measured with the Zeiss Comparator, No. 873, principally used by the writer for the measurement of stellar spectra. The instrument has a scale graduated to 0.2 mm, which moves with the plate and may be read by a second microscope and micrometer to one micron (0.001 mm). A magnifying power of 13 was commonly employed in the microscope with which the plate was observed. The length of the spectrum included on the plates taken with the prism-train was 75 mm. On the plates taken with the concave grating the focus was sufficiently good for measurement over about 40 mm. The linear scale of the prism plates was slightly more than four times that of the grating plates for the region between $\lambda 4340$ and $\lambda 4215$.

Either two or four settings were made on each line, the line being alternately brought under the micrometer "thread" (a line ruled on the glass reticle extending half way across the field) from the left and from the right. The parallel, or line in the direction of the length of the spectrum along which the settings were made, was so selected that both the short and the long bright lines could be measured, without involving the end of the "thread" or pointer in the streak of continuous spectrum near the center of the two plates of the second flash, and on the two plates of the cusp. There were no such streaks of continuous spectrum on the two plates of the first flash, so that the settings were made on the parallel through the center of the spectrum, or at the solar position angle of the point of second contact, computed to be 68°. The measurements of the second flash (prism plate) were made at about position angle 278°, and on the grating plate at about 269°. The lines in the spectrum of the cusp ten seconds before totality were measured at about 100°, and on the cusp after totality at about position angle 240°.

On account of the peculiar tendency of the crescents to shade off from sharpness on the side toward the red to diffuseness

on the side toward violet, both for plates taken with prisms and with the grating, it became necessary to make the settings on the red side. Thus the settings were made on the convex sides of the crescents on the plates taken at third contact and on the cusp plate following. Hence unless the crescents or lines are all of equal width, a systematic correction has to be applied to the wave-lengths of the lines on those plates, in order that they may not be in error by an amount corresponding to the thickness of the stratum producing the line or crescent. However, as the measures were made along parallels at some distance from the position angle of third contact, most of the crescents run to a point, and the correction therefore depends upon the thickness of the standard lines at the parallel.

The estimates of the intensities of the lines were made as the lines were measured, and are of course quite rough. Both the intensity proper, for a given width of line, and the whole width, enter into the estimate, which might perhaps be regarded as the product of intensity and width. The scale is purely arbitrary, a line just fairly visible being recorded as of intensity 10, while for the large hydrogen crescents the estimate runs up to 500. The range of width × intensity is much larger for the chromospheric lines than for the dark lines of the solar spectrum. Despite the difference between this scale of intensity and that of Rowland's table, the comparison of the two is not at all difficult, and an examination of the table will show that the majority of strong lines of the chromosphere are also strong on Rowland's map.

REDUCTION OF THE PLATES.

The measures on the plates obtained with the objective-prism were reduced to wave-lengths by the use of the Cornu-Hartmann formula. There was considerable embarrassment in selecting the three standard lines on which the interpolation formula is based. From the experience of other observers of eclipse spectra it was inferred that it was unsafe to assume the identity of any but a few of the most conspicuous chromospheric lines, especially those of hydrogen. But these lines were very broad

and diffuse toward the violet, involving a considerable correction for the plates of the second flash and second cusp. In spite of this it seemed necessary, however, to adopt as standards lines whose identity was unquestioned, and the choice was made of $H\gamma$ (λ4340.63) and the two very strong strontium lines at λ4215.70 and λ4077.89. On account of its fracture near $H\gamma$ the plate of the first flash had to be reduced in two parts, the strong iron line at λ4325.94 being used with the two strontium lines for standards for the larger part of the plate, while for the end toward red, containing only about a dozen bright lines, the iron lines at λ4383.72 and λ4404.93 and the titanium line at λ4417.88 served as standards. Measures on the other plates confirmed the correctness of the identification of these strong lines of the Fraunhofer spectrum with the bright lines on the plate.

In the case of the plate of the solar cusp taken ten seconds before totality, dark lines had to be used as standards. They were, for the violet side of the plate, λ4071.91, 4132.24, and 4271.93; for the other part of the plate λ4308.02, 4325.94, and 4415.29. By basing the wave-lengths of this plate upon the dark lines as standards, a slight lack of homogeneity is introduced, involving a difference in these wave-lengths of the order of any possible displacement of the bright lines with respect to the dark. But as there appeared to be no differences which would affect the result by more than a very few hundredths of a tenth-meter, these values of the wave-lengths have been given the same weight as the others in taking the final mean.

The numerical value of the correction to be applied to the wave-lengths of Flash II and Cusp II, on account of the fact that the measures were made on the convex instead of the concave side of the crescents, or at the top instead of the base of the strata of which the crescents are the images, was determined from measurement of the thickness of the crescents of the standard lines at the parallel along which the settings were made. From these measures correction curves were drawn, varying from +0.13 to +0.24 tenth-meters for Cusp II, and from +0.17 to +0.25 for Flash II, increasing from the end of the plate of

shorter wave-lengths. These corrections were found to be in good agreement with the values suggested by the systematic differences between the wave-lengths of Flash I and Flash II. In the case of the broadest lines, whose width was a considerable fraction of that of the three standard lines, the amount of the correction was diminished by a quantity depending upon the actual thickness of the line in question as measured on Flash I, on which plate the settings were made on both edges. In the case of the grating plate of the second flash a constant correction of $+0.2$ tenth-meter was applied.

After the tables had been made out in the form given below, and many of the finer lines had been identified with dark lines of Rowland's tables, new formulae were calculated for the violet ends of the plates of Flash II and Cusp II, narrow lines being used as standards. The wave-lengths thus determined accorded so closely (usually within five hundredths of a tenth-meter) with the "adopted wave-lengths" of the table, that the tables were left unchanged.

On account of the smaller linear dispersion of the plates taken with the concave grating, and on account of the falling off in sharpness of focus on both sides of the center of the plates, due to the necessary use of plane instead of curved plates, a lower degree of accuracy was to be expected in the determination of wave-lengths with the grating than with the prism-train. Accordingly it seemed undesirable to reduce the grating plates by any more elaborate process than by treating each in three sections, through each of which the spectrum was assumed to be normal. Fourteen lines were selected as standards, as follows: $\lambda 4215.70$ (*Sr*), 4226.90 (*Ca*), 4274.96 (*Cr*), 4289.88 (*Cr*), 4307.90 (*Ca*), 4383.72 (*Fe*), 4471.65 (*He*), ($H\gamma$ was used instead of $\lambda 4383$ on Flash I), $\lambda 4501.44$ (*Ti*), 4554.21 (*Ba*), 4563.94 (*Ti*), $\lambda 4572.16$ (*Ti*), 4713.25 (*He*) and 4861.53 ($H\beta$). The constants a and b of the linear equation $\lambda = ax + b$ were deduced by least squares for each section. The residuals for the standard lines of the middle section average for Flash I, 0.05 tenth-meters; for Flash II, 0.08. For the outer sections the residuals

are larger, averaging for the section toward violet 0.21, and for the section toward red 0.24. Hence the wave-lengths of the few lines beyond λ 4600 (toward the red) may be uncertain by a considerable fraction of one tenth-meter.

DESCRIPTION OF THE TABLES.

The results of the measures are collected in the following tables. The first eight columns contain the wave-lengths as deduced from the measurement of the four plates concerned (before any systematic corrections have been applied) with the intensities of the lines as roughly estimated on a scale as described above. The column entitled "adopted wave-length" represents the mean of the different values, after the systematic corrections had been applied to the measures on the plates of the second flash and second cusp. The last three columns, giving the comparison with the dark line, or Fraunhofer spectrum, are extracted from Rowland's "Table of Solar Spectrum Wave-lengths" published in this JOURNAL, Vols. I to V, except that the wave-length of the helium lines, which are not visible as dark lines in the solar spectrum, are taken from the paper by Runge and Paschen (this JOURNAL, Vol. III, p. 3). In this comparison only the stronger lines from Rowland's table which fall within 0.2 tenth-meter (or usually less), and for which the identification seems tolerably certain, have been given. Many more of the lines could be identified with fainter lines of Rowland's list, but with less certainty as to the identity, and doubtless quite a number of the identifications given above are incorrect, based upon an accidental coincidence of the bright and dark lines.

The letter h signifies that the bright line was hazy or diffuse; v h that the line was very hazy; l that it was a long line or arc; s denotes sharp, and d double. Rowland's scale of intensities runs from 1, a line just clearly visible on his map, to 1000 for the H and K lines. Below 1 the scale of faintness proceeds from 0 to 0000. N indicates that the line is not clearly defined or that it is much weaker than it should be for its breadth. Where two or more elements are given under the column entitled Substance, the solar line is compound.

BRIGHT LINES MEASURED ON SPECTRA

Flash II		Cusp II		Flash I	
λ	I	λ	I	λ	I
		4024.3	6 v h		
		4024.8	8		
4026.2	80	4026.1			
4028.1	35 s	4028.2	20		
		4029.5			
4031.5	30	4031.6	15		
4032.8	50				
4034.3	60				
4035.4	60	4035.5			
4040.6	50 s	4040.6	30		
4042.8	60 h	4042.8	8		
		4044.3	8		
4045.7	200	4045.5	h l		
4048.6	40	4048.6			
4053.7	12 s				
4054.8	40	4054.8			
4058.8	25				
4061.0	30 s	4061.0	15		
		4062.4	8		
4063.6	50				
		4066.6	6		
		4067.9	10		
4071.8	60	4071.8	40	4071.7	40 s
4075.8	15				
4077.89	200	4077.89	300	4077.89	200 s
4078.4	15				
4081.2	10	4081.3			
4086.3	15	4086.4	9		
4086.8	30 s	4086.8	17 s		
4090.5	12				
4091.4	4				
4092.4	30 h	4092.4	12		
4096.1	15				
4096.7	6 d				
4098.1	4				
4098.2	5				
4098.6	6				
4102.2	500	4102.1	400	4102.2	400
4103.0	25	4103.0	17		
4104.2	15 s	4104.2	12		
4107.5	40 d ?	4107.6	12 d ?		
4109.5	30 v h	4109.2	20		
		4109.9	10		
4110.6	60 h	4110.6	20 h		
4111.4	20 s	4111.4	10		
4111.8	8				
		4113.8	10		
4114.6	20	4114.5			
4115.4	30 h	4115.4	h		

TAKEN WITH PRISM-TRAIN.

Cusp I		Adopted Wave-length	Comparison with Rowland's Table		
λ	I		λ	Substance	I
		4024.4	4024.25	*Fe*	2
		4024.9	{ 4024.73 4024.88	*Ti* *Fe*	3 } 4 }
		4026.28	4026.34	*He*	
		4028.28			
		4029.6			
		4031.70			
		4032.9	4032.79	*Fe*	4
		4034.4			
		4035.60			
		4040.75	4040.79	*Fe*	3
		4042.93	4042.74	*Cr, Nd*	0
		4044.4			
		4045.76	4045.98	*Fe*	30
		4048.76			
		4053.9	4053.98	*Fe-Ti*	3
		4054.98	4055.02	*Fe*	3
		4059.0	4058.92	*Fe, Cr*	3
		4061.18	4061.24	*Nd–*	3
		4062.6	4062.60	*Fe*	5
		4063.8	4063.76	*Fe*	20
		4066.8			
		4068.1	4068.14	*Fe-Mn*	6
		4071.88	4071.91	*Fe*	15
		4076.0	4076.10	*Fe*	3
4077.9	150	4077.89	4077.89	*Sr*	8
		4078.6	{ 4078.52 4078.63	*Fe* *Ti*	4 } 3 }
		4081.43			
		4086.52	4086.47	*Co–*	3 d ?
		4086.99	4086.86	*La*	1
		4090.7			
		4091.6	4091.71	*Fe*	3
		4092.6	4092.43	*Fe*	2
		4096.3	4096.13	*Fe*	3
		4096.9			
		4098.3			
		4098.4	4098.34	*Fe*	5
		4098.8	4098.69	*Ca ?*	4
4101.9	300	4102.11	4102.00	*H*	40 N
		4103.20	4103.10	*Si, Mn*	5
		4104.40	4104.29	*Fe*	5
		4107.76	4107.65	*Ce-Fe-Zr*	5
		4109.57	4109.22	*Fe*	3
		4110.1	4109.95	*Fe*	3
		4110.81	4110.69	*Co*	4
		4111.63			
		4112.0	4111.94	*V*	4
		4114.0			
		4114.73	4114.61	*Fe*	4
		4115.58	4115.33	*V*	3

Flash II		Cusp II		Flash I	
λ	I	λ	I	λ	I
4118.8:		4118.6:	h		
4119.4	10 s				
4119.9	7				
		4121.1	3		
4121.4	20	4121.4	15 sl	4120.9	15
4122.8		4122.8	12		
4123.2	18	4123.4	25 sl		
4124.0	8	4124.0	8		
4124.9	h	4124.9	15		
		4125.7	5		
4126.6	8				
4127.7	8	4127.4	h		
4128.1	12	4128.2	h		
4128.8	15	4128.8	6		
4129.6		4129.3	7		
4129.8	30	4129.9	20		
4130.7	15	4130.8	8		
4132.2	h	4131.8	8 d?	4132.2	10
4132.8	10				
4133.4	6				
4133.9	20	4134.0	6		
4134.8	40	4134.7	20		
4135.5	10	4135.5	5		
4137.1	20	4137.1	3		
4139.0	6	4139.1	2		
4139.6	10				
4140.5	8	4140.8	4		
4142.9	7				
4143.2	7	4143.2	7		
4143.9	15			4143.9	30 h
4146.3	60				
4147.7	7	4147.8	30		
4149.3	40 s	4149.4	18	4149.3	15
4150.0	dark line	4150.0	9		
4151.0	30 s	4150.9	5		
4152.2	80 h	4152.1	12 l		
4154.8	50	4154.6	4		
4156.2	40	4156.3	20 h	4156.2	5
4156.8	15			4156.6	7
4158.1	15				
		4160.4	3		
		4161.3	9	4161.1	d?
4161.6	80 h	4161.6	5		
		4162.0	5		
4162.6	10	4162.3	5	4162.7	7
				4163.2	
4163.7	50	4163.8	12	4163.7	30
4164.3	12			4164.6	5
				4165.1	6
				4165.8	6

Cusp I		Adopted wave-length	Comparison with Rowland's table		
λ	I		λ	Substance	I
		4118.89	4118.71 4118.93	*Fe* *Co*	5 4
		4119.6			
		4120.1			
		4121.3			
		4121.36	4121.48	*Cr-Co*	6 d ?
		4123.00			
		4123.50	4123.38 4123.54	*La* *V*	12 0
		4124.19			
		4125.10			
		4125.9	4125.78	*Fe*	3
		4126.8	4126.67	*Cr*	2
		4127.72	4127.77	*Fe*	4
		4128.37	4128.25	*V–*	6 d ?
		4129.01			
		4129.65	4129.62		2
4129.9	20	4130.01			
		4130.92	4130.80	*Ba*	2
		4132.19	4132.24	*Fe*	10
		4133.0	4133.06	*Fe*	4
		4133.6	4133.76	*Fe*	2
		4134.11	4134.01	*Fe*	3
4134.7	10	4134.86	4134.84	*Fe*	5
		4135.69			
		4137.31	4137.16	*Fe*	6
		4139.25	4139.24		0
		4139.8			
		4140.84			
		4143.1			
		4143.41			
		4143.99	4144.04	*Fe*	15
		4146.5			
		4147.87	4147.84	*Fe*	4
		4149.47	4149.53	*Fe*	4
		4150.2			
		4151.18	4151.13	*Zr, Ti*	1
		4152.35	4152.34	*Fe*	3
		4154.90	4154.67 4154.98	*Fe* *Fe*	4 4
4156.2	20	4156.34	4156.39	*Zr*	1
		4156.84	4156.83		1
		4158.3			
		4160.6			
		4161.19	4161.24		2
		4161.81	4161.68		4
		4162.2			
		4162.69	4162.62		1 N
		4163.4			
		4163.86	4163.82	*Ti, Cr–*	4
		4164.55			
		4165.1			
		4165.8	4165.76	*Ce,–*	2

Flash II		Cusp II		Flash I	
λ	I	λ	I	λ	I
		4167.3	4	4167.1	8
				4167.6	4
				4168.2	6
4171.1	20	4171.1	15		
4172.0	80	4172.1	15	4171.9	30
4173.5	50	4173.6		4173.5	35
		4174.8	5		
4175.4	10 h	4175.6	6		
4175.7	10 h				
4176.6	3 d ?	4176.6	7		
4177.6	70	4177.7	40	4177.7	40
4179.0	60	4179.0	15	4178.9	25
4179.5	45	4179.4	12		
4180.9	6	4181.0	9	4180.9	4
4181.8	15	4181.8	15		
4182.2 ?	8	4182.5	10		
		4182.8	8		
		4183.3	6		
4184.1	7	4184.0	7		
4184.3	7	4184.4	8		
4185.0	15	4185.0	12		
4185.3	4	4185.4	4		
		4186.1	5		
4186.6	12	4186.7	10		
4187.2	15	4187.1	15 d ?	4187.0	9
4188.0	20	4187.9	15	4187.7	4
4188.7	10				
4189.5	12	4189.6	8		
4190.1	3	4190.0	6		
4190.6	5	4190.7	6		
		4191.0	5		
4191.6	40	4191.5	15	4191.3	6
				4192.0	5
4193.1	5				
4193.7	3				
4194.8	7	4194.9	5		
4195.2	6				
4196.4	6	4196.6	7		
4198.4	20			4198.7	8
4199.2	20	4199.3	7	4199.1	12
4200.6	25 d				
4202.1	40			4202.1	25
4202.9	18	4202.8	6		
4203.9	15	4204.1	4		
4205.0	35	4205.1	15		
4206.6	10	4206.7	7		
		4207.2			
4209.0	20	4209.1	12	4208.9	8

Cusp I		Adopted Wave-length	Comparison with Rowland's Table		
λ	I		λ	Substance	I
		4167.31	4167.44		8
		4167.6			
		4168.2			
		4171.30	4171.21	*Ti*,–	4
		4172.15	4172.07	*Ti*, *Fe*	2
		4173.75	4173.71		3
		4175.0	4175.08	*Fe*	5
		4175.74	4175.81	*Fe*	5
		4175.9			
		4176.80	4176.74	*Fe–Mn*	5
		4177.80	{ 4177.70	*Fe*	3 }
			{ 4177.77		3 }
		4179.08	4179.02		3
		4179.69	4179.54	*V*,–	3 d ?
		4181.67	4180.97	*C*	2 N
		4182.02	4181.92	*Fe*	5
		4182.6	4182.55	*Fe*	3
		4183.0			
		4183.5			
		4184.28	4184.16		4
		4184.58	4184.47		2
		4185.19	4185.06	*Fe*, *Cr*	4
		4185.61			
		4186.3			
		4186.87			
		4187.27	4187.20	*Fe*	6
		4188.04	{ 4187.94	*Fe*	5 }
			{ 4188.02		3 }
		4188.9	4188.89		4
		4189.77	4189.72	*C*,–	2
		4190.30	4190.29	*Cr*	0 N
		4190.88	4190.87	*C*, *Co*	1 N d ?
		4191.2			
		4191.68	4191.60	*Fe*	6
		4192.0			
		4193.3			
		4193.9	4193.96	*C*	0
		4195.07	4195.01	*Cr*	1
4195.7	12	4195.60	{ 4195.49	*Fe*	5 }
			{ 4195.68		1 }
		4196.73	4196.70	*La*	2
		4198.66	4198.56	3 lines, 2 *Fe*	4, 4, 3
		4199.35	4199.27	*Zr–Fe*	5
		4200.8	{ 4200.61	*Ni*	1 }
			{ 4200.76		1 }
		4202.22	4202.20	*Fe*	8
		4203.06			
		4204.01	4204.10	*Fe*	3
4205.1	20	4205.23	4205.24		1
4206.9	15	4206.88			
		4207.4			
		4209.14	4209.14	*Zr*	1

Flash II		Cusp II		Flash I	
λ	I	λ	I	λ	I
4210.4	30				
4211.9	25	4211.8	12		
4213.7	15	4213.6	7		
4214.9	12				
4215.7	100	4215.7	40	4215.7	
4217.5	v h	4217.2	6		
		4217.6	7		
4218.5	6			4218.4	5
4219.3	18	4219.4	12		
4220.3	12	4220.3	15		
4221.4	6				
4222.5	v h	4222.5	group		
		4223.0	6		
4224.0	5				
4224.3	6	4224.2	6		
4225.2	6	4225.4	15		
4226.8	100	4226.8	50	4226.8	100
4227.4	20	4227.4	15		
4230.9	8	4231.1	8		
		4232.4	4		
4233.2	90	4233.2	40	4233.2	30
4233.5	5	4233.6	5		
4235.2	12	4235.2	10	4235.3	8
4236.0	40	4235.9	12	4236.0	9
		4237.2	4		
		4237.9	8		
4238.6	8	4238.4	5		
		4238.8	9		
4239.8	15	4239.8	10		
4242.4		4242.5	15		
4243.1	8	4243.4	1		
4245.1	12	4245.1	8		
4245.8	10			4246.0	
4246.8	75	4246.9	35	4246.9	80
4247.3	10	4247.3	7		
4248.1	10				
4250.1	18	4250.1	12	4250.1	15
4250.6	25	4250.7	12	4250.8	15
4251.6	8	4251.8	7		
4254.3	80	4254.3	25	4254.4	50
		4254.9	8 s		
4255.5	6				
4256.1	11	4256.3	6		
4257.0	4				
4257.5	7				
4258.0	20	4258.2	10		
4258.9	6				
4259.1	4				
4260.4	40	4260.4	20	4260.5	35

Cusp I λ	Cusp I I	Adopted Wave-length	Comparison with Rowland's Table λ	Substance	I
		4210.6	4210.49 4210.56	*Fe*	4 3
		4212.09	4212.05	*Zr*	2
		4213.90	4213.81	*Fe*	3
		4215.1			
4215.6		4215.70	4215.70	*Sr*	5 d?
		4217.5			
		4217.8	4217.72	*La, Fe-Cr*	5 d?
		4218.62	4218.56	*-Zr*	1 N d
		4219.59	4219.52 4219.58	*Fe*	4 3
4220.3		4220.46	4220.51	*Fe*	3
		4221.6	4221.63		1 N
		4222.74			
4223.0	30	4223.1			
		4224.2			
		4224.47	4224.34	*Fe*	4
		4225.52	4225.62	*Fe*	3
4226.6	40 h	4226.82	4226.90	*Ca*	20 d?
		4227.67	4227.61	*Fe*	4
		4231.24	4231.18	*Ni*	4 N
		4232.6			
4233.3		4233.28	4233.33	*Mn-Fe*	4
		4233.78	4233.77	*Fe*	6
		4235.37	4235.30 4235.45	*Mn* *Mn*	2 3
		4236.10	4236.11	*Fe*	8
		4237.4	4237.34	*Fe*	3
		4238.1	4238.19	*Fe*	3
		4238.73			
		4239.0	4238.97	*Fe*	5
		4240.03	4240.01	*Fe*	3
		4242.67	4242.62		2
		4243.50	4243.52 4243.61	 *Fe*	1 3
		4245.37	4245.42	*Fe*	4
		4246.0			
4247.0		4246.97	4247.00	*Y?*	5
		4247.56	4247.59	*Fe*	4
		4248.3	4248.38	*Fe*	2
		4250.24	4250.29	*Fe*	8
		4250.89	4250.95	*Fe*	8
		4251.93			
4254.7		4254.51	4254.51	*Cr*	8
		4255.1	4255.13	*Fe*	2 d?
		4255.7	4255.66	*Fe, Cr*	1
		4256.44			
		4257.2			
		4257.7			
		4258.32			
		4259.1	4259.11	*Fe*	2
		4259.3			
		4260.61	4260.64	*Fe*	10

Flash II		Cusp II		Flash I	
λ	I	λ	I	λ	I
		4261.2	12		
4261.8	25	4261.9	10		
		4262.6	4		
		4263.0	3		
4265.6	? 12	4265.9	7		
4266.8	20 d ?				
4268.5	8	4268.3			
		4269.9	7		
4271.0	20	4271.2	15	4271.1	9
4271 7	25	4271.7	35	4271.8	40
4272.7	6				
4273.2	20	4273.2	6		
4274.7	75 d ?	4274.7	30	4274.8	60
4275.4	20	4275.5	8		
4277.3	4				
4277.9	6 d ?	4278.0	3		
4279.6	8				
4280.5	5				
4282.2	25	4282.4		4282.5	12
4282.7	10			4282.8	15
4284.0	12	4284.0	6		
4284.6	3				
4285.2	8	4285.3	5		
4285.8	6				
4286.2	8	4286.4	5		
4286.6	3				
4287.7	25	4287.8	25	4287.7	12
4288.4	6	4288.6			
4288.7	4				
4289.6	40	4289.7	10	4289.7	50
4290.1	40	4290.2	20	4290.3	25
4290.9	12 d ?	4290.8	12		
4291.8	10	4292.0	18		
4292.9	7	4293.0	7		
4293.9	70	4294.0		4294.2	60
4294.5	7				
4294.9	5				
4295.8	7	4295.6	15		
4296.6	20	4296.5	20	4296.5	6
4299.0	5				
4299.9	60	4299.9	20	4300.1	50
4301.7	40	4301.7	15	4302.0	25
4302.2	12	4302.5	8		
4302.8	15	4303.0	12	4302.6	
4303.9	5	4303.4	8	4303.2	12
4304.2	5	4304.4	10		
4305.4	40				
4306.5	10	4306.6	12		
4307.8	50	4307.8	15	4308.0	45

Cusp I. λ	Cusp I. I	Adopted Wave-length	Comparison with Rowland's Table λ	Substance	I
		4261.4	4261.38		2
		4262.09	4262.09		1
		4262.8			
		4263.2	4263.29	*Ti, Cr*	2
		4266.0	4266.08	*Mn*	2
		4267.0	4267.12	*Fe*	3
		4268.65			
		4270.1			
		4271.24	4271.33	*Fe*	6
		4271.89	4271.93	*Fe*	15
		4272.9			
		4273.48	4273.48	*Fe*	3 N
		4274.93	4274.96	*Cr*	7 d ?
		4275.72			
		4277.5			
		4278.21			
		4279.8	4279.87		2 N d ?
		4280.7			
		4282.50	4282.57	*Fe*	5
		4282.88	4282.86	*Ti*	0
		4284.27	4284.22 4284.38	*Mn, V*	0 2 N d ?
		4284.8	4284.84	*Ni*	1
		4285.50	4285.53 4285.61	 *Fe*	1 3
		4286.0			
		4286.58	4286.63		3 N.
		4286.8			
		4287.91	4288.04	*Ti*	2
		4288.7			
		4288.9			
		4289.82	4289.89	*Cr*	5
		4290.34	4290.38	*Ti*	2
		4291.11	4291.11	*Ti*	3
		4292.15	4292.14	*Cr, V*	0
		4293.17	4293.19		2
4294.5		4294.41	4294.30	*Fe*	5
		4294.7			
		4295.1			
		4295.98	4295.91 4296.04	*Cr, Ti* *Ni*	2 1
4296.4		4296.72	4296.74		3
		4299.2	4299.15	*Ca*	3
4300.49		4300.36	4300.38	*Mn*	0
		4301.96	4302.09	*Ti*	2
4302.3		4302.31	4302.35	*Fe*	2
		4302.95	4302.91		2 N
		4303.70	4303.75		1
		4304.51	4304.55		1
		4305.6	4305.61	*Fe, Sr, Ti, Cr*	3
		4306.80	4306.86		2
		4308.01	4307.91 4308.08	*Ca* *Fe*	3 6

Flash II		Cusp II		Flash I	
λ	I	λ	I	λ	I
4308.6	5				
4309.4	30	4309.4	30	4309.8	12
4309.9	2				
4311.1	3	4311.4	6		
4312.7	40	4312.8	25	4313.0	
4313.3	8	4313.5	8		
4314.0	40	4314.0	20	4314.3	40
4314.9	40	4314.8	30	4315.1	35
4316.5	12	4316.6	6		
4317.0	6				
4318.5	20	4318.7	12	4318.8	4
		4319.5	6		
4320.7	60	4320.7	50 l	4320.9	45
4321.3	12	4321.6	8		
4322.8	7 h d ?	4323.0			
4324.8	40	4324.9	20	4325.1	20
4325.6	50	4325.6	30	4325.9	55
4326.8	15				
4327.6	7 h	4327.8	10		
4330.5	30 v h	4330.5	h		
4331.2	15 h				
		4332.7	6		
4333.5	25	4333.6	18	4333.0	15
4334.4	12				
4335.8	8				
4336.6	15	4336.1	6		
4337.6	25 s	4337.7	20		
		4339.2	12		
4340.63	400	4340.63	400		
4341.4	? 3	4341.9	8		
4342.9	10	4342.9	6		
4343.3	5	4343.4	5		
		4343.7	5		
4344.2	50	4344.2	25		
4345.6	8 h				
4347.5	25				
4348.6	7				
4351.5	60	4351.6	40		
4352.4	40	4352.6	30		
		4353.5	5		
4354.2	15	4354.3	12		
4357.7		4357.9			
4358.4	20 h	4358.5			
4359.4	40	4359.5	30		
4359.8	15 h				
4361.6	15				

Cusp I		Adopted Wave-length	Comparison with Rowland's Table		
λ	I		λ	Substance	I
		4308.8	4308.76		2 N d ?
		4309.71			
		4310.1			
		4311.50			
		4312.99	4313.03	*Ti*	3
4313.4	10	4313.55			
4314.12	10	4314.36	4314.25	*Sc*	3
4315.2	20	4315.28	{ 4315.14	*Ti*	3 }
			{ 4315.26	*Fe*	4 }
		4316.79			
		4317.2			
4319.2	15	4319.02	4318.82	*Ca, Mn?*	4
		4319.7			
4321.0	25	4321.06	{ 4320.91	*Sc*	3 }
		4321.72	{ 4321.12		2 }
		4323.1			
		4325.18	4325.15	*Sc*	4
4325.9	15 l	4326.03	4325.94	*Fe*	8
		4327.0			
		4328.06	4328.08	*Fe*	2
		4330.71			
		4331.4			
		4332.9			
		4333.54			
		4334.6			
		4336.0			
		4336.6			
4338.2	15	4337.99	{ 4337.95	*Sr?*	00 }
			{ 4338.08	*Ti*	4 }
4339.4	10	4339.42			
		4340.63	4340.63	*H*	20 N
		4342.1			
		4343.17			
		4343.56			
		4343.9	4343.86	*Fe*	2
		4344.42	4444.45	*Ti*–	2
		4345.8			
		4347.7	4347.71		1 N
		4348.8			
4351.8	15 l	4351.79	{ 4351.71	*Fe*	2 }
			{ 4351.93	*Cr*	5 }
		4352.75	4352.91	*Fe*	4
		4353.7			
		4354.47			
		4358.0			
		4358.70	4358.67	*Fe*	2
		4359.72	4359.78	*Cr*	3
		4360.0			
		4361.8			

Flash II		Cusp II		Flash I	
λ	I	λ	I	λ	I
4362.8	10				
4363.6	6	4364.0	8		
4364.3	8				
4365.9	5				
4367.3	25 h	4367.5	15		
4369.0	12				
4369.3	15	4369.4	25 d ?		
4370.8	20 d ?	4370.8	20		
4371.8	4				
4372.4	5				
		4373.7	6		
4374.7	60	4374.8	30	4374.5	12
4375.6	40	4375.8	20	4375.0	15
4376.3	5			4376.0	6
4376.8	15				
4378.8	30				
4380.3	15				
4381.3	10				
				4383.7	20
				4395.2	35
				4399.9	7
				4400.5	5
				4404.9	25
				4415.7	4 d
				4416.9	7
				4417.9	12 l
				4427.4	8

TABLE OF LINES MEASURED ON PLATES TAKEN WITH THE CONCAVE GRATING.

The table is in two parts. The first includes thirty-five lines in the spectral region covered by both the prism train and the grating. All but two of these lines have been given above from the measures on the prism plates, and accordingly the comparison with Rowland's table is not repeated, but the last column gives the difference, to the nearest tenth of a tenth-meter, between the wave-length found from the prism plates and the mean wave-length given in the third column which is obtained directly from columns first and second. This difference exceeds 0.2 tenth-meter in only four cases. When averaged with the wave-lengths above obtained on the prism-plates, with the

Cusp I λ	Cusp I I	Adopted Wave-length	Comparison with Rowland's Table λ	Substance	I
		4363.0			
		4364.0			
		4364.5			
		4366.1			
		4367.64	4367.75	*Fe*	5
		4369.2			
		4369.6	4369.94	*Fe*	4
		4371.0			
		4372.0			
		4372.6			
		4373.9			
		4374.8			
4375.2	25 l	4375.5			
		4376.3	4376.11	*Fe*	6
		4377.0			
		4379.1			
		4380.5			
		4381.5			
		4383.7	4383.72	*Fe*	15
4395.3	25	4395.27	4395.20	*Ti*	3
		4399.9	4399.94	*Ti, Cr*	3
		4400.5	4400.56	*Sc*	3
		4404.9	4404.93	*Fe*	10
		4415.7			
		4416.9			
4418.2	12	4418.0	4417.88	*Ti*–	3
4425.8	7	4425.8			
		4427.4			

proper weights, the change in the adopted wave-length in the previous table would not be affected in any case enough to change the identification with lines in Rowland's table. Two lines, at λ 4387.9 and at about λ 4398, were not measured on the prism plates. They do not appear to be readily identifiable with any of the stronger ones of Rowland's lines. The letter N is used to signify the normal or standard lines, fourteen in number, by which the wave-lengths were reduced. The Rowland values of their wave-lengths are given instead of the values computed from the least square solution, which, of course, would differ slightly from them. As explained above, a constant correction of +0.2 tenth-meters has been applied to all the wave-lengths measured on Flash II. A colon indicates that the measures on a line were recorded in the original notes as rough or uncertain.

In the second part of this table the comparison with Rowland's table is given in the same manner as in case of measures on the prism plates.

BRIGHT LINES MEASURED ON SPECTRA TAKEN WITH CONCAVE GRATING.

I. LINES ALSO OBTAINED WITH PRISM-TRAIN.

Flash I		Flash II		Mean λ	Difference Prisms-Grating λ
λ	I	λ	I		
N	90	N	70	4215.70	0.0
N	60	N	45	4226.90	0.0
4233.3	12	4233.4	30 h	4233.4	−0.1
4246.9	50 l	4247.2	35	4247.1	−0.1
4250.5	7 h	4250.2:	3	4250.4:	−0.2
4254.5	35	4254.5	25 s	4254.5	0.0
		4258.1	7	4258.1	+0.2
4260.7	8	4260.3:	10 h	4260.5:	+0.1
4271.8	18	4271.8	12	4271.8	+0.1
N	30	N	20	4274.96	0
N	45	N	30	4289.88	0
4294.2	25	4294.4	20	4294.3	+0.1
4300.4	30	4300.2	25	4300.3	+0.1
		4303.3	30	4303.3	[0.0 pair]
		4305.6	5	4305.6	0.0
N	25	N	25	4307.90	+0.1
4313.2	11	4312.8	15	4313.0	0.0
4314.4	14	4314.9	35	4314.4	0.0
4315.3	12			4315.3	0.0
		4318.6	7	4318.6	+0.4
4321.0	20 s	4321.1	25	4321.1	−0.3
4325.8	25 h	4325.7	40 d?	4325.8	+0.2
4328.5	15 l				−0.4
N				4340.63	0.0
		4344.1	10 s	4344.1	+0.3
4352.2	30 l	4352.0	45	4352.1	[+0.2 pair]
		4359.5	15 h	4359.5	+0.2
4375.1	20	4374.9	25	4375.0	[+0.1 pair]
		N		4383.72	0.0
4387.9	10 d			4387.9	—
4395.2	50 l	4395.3	50	4395.2	+0.1
		4397.8:	8	4397.8:	—
4400.2	25	4400.4	30	4400.3	+0.2
N	18	4404.8	20	4404.93	0.0
4417.8	18 h	4418.2	30 h	4418.0	0.0

II. LINES BEYOND LIMIT OF PRISM SPECTRA.

Flash I		Flash II		Mean λ	Comparison with Rowland's Table		
λ	I	λ	I		λ	Substance	I
		4408.1:	8	4408.1:	4407.87	*Fe*	4
4415.6	12	4415.2	20	4415.4	4415.29	*Fe*	8
4427.5	12 h	4427.2	12	4427.4	4427.27	*Ti*	2
					4427.48	*Fe*	5
		4429.7	8	4429.7			
4435.0	10 d?	4435.3	10	4435.2	4435.13	*Ca*	5
					4435.32	*Fe*	2
4444.0	40	4444.0	35	4444.0	4443.98	*Ti*	5
4450.6	18	4450.6	20	4450.6	4450.65	*Ti?*	2
4454.9	12	4454.9	20 h	4454.9	4454.95	*Ca, Zr*	5
		4457.8	5	4457.8	4457.60	*Ti, V, Zr,*	2
					4457.71	*Mn*	2
4461.9	7	4461.7	15 d	4461.8	4461.82	*Fe*	4
4464.6	6	4464.6	12	4464.6	4464.62	*Ti?*	2
4468.8	50	4468.8	30 s	4468.8	4468.66	*Ti-*	5
N		N	100	4471.65	4471.65	*He*	
		4482.1		4482.1			
		4489.2	8	4489.2			
		4491.4	10	4491.4			
		4494.5	8	4494.5			
		4496.3:	6 d	4496.3:			
N	35 l	N	35 l	4501.44	4501.44	*Ti,-*	5
4508.7	7	4508.0	15	4508.4	4508.66	*Fe?,-*	4
		4511.7	4	4511.7			
4515.5	10	4515.3	12 h	4515.4	4515.51		3
		4518.0	5	4518.0			
4520.5	8	4520.3	17	4520.4	4520.40	*Fe?,-*	3
4522.9	15	4522.7	25 l	4522.8	4522.80		3
					4522.97	*Ti*	2
		4525.0	7	4525.0	4525.31	*Fe*	5
		4528.6:	5	4528.6:	4528.80	*Fe*	8
4534.2	40 l	4534.3	60	4534.2	4534.14	*Ti-Co*	6
4549.8	40 l	4550.0	55	4549.9	4549.81	*Ti-Co*	6 d?
N	50 l	N	55	4554.21	4554.21	*Ba*	8
		4556.1	10	4556.1	4556.31	*Fe-Cr*	4
4559.0	15	4558.8	15	4558.9	4558.83	*Cr?*	3
N	30	N	40 d	4563.94	4563.94	*Ti*	4
N	45	N	45	4572.16	4572.16	*Ti*	6
		4580.1:	5	4580.1:	4580.23	*Cr*	3
4584.1	25 l	4584.1	35 s	4584.1	4584.02	*Fe-*	4
4588.3	15 s	4588.1	13 l	4588.2	4588.38		3
4590.1	12	4590.1	10 l	4590.1	4590.13		3
		4616.3	15	4616.3	4616.31	*Cr*	4
4619.0	8	4618.7	12	4618.7			
		4619.8	6	4619.8			
4626.6	6			4626.6			
		4629.4	45 l	4629.4	4629.52	*Ti-Co*	6
4631.7	12			4631.7			
		4633.8	10	4633.8			
		4646.2	12 l	4646.2	4646.35	*Cr*	5

II. LINES BEYOND LIMIT OF PRISM SPECTRA.—*Continued.*

Flash I		Flash II		Mean λ	Comparison with Rowland's Table		
λ	I	λ	I		λ	Substance	I
		4651.1	7 l	4651.1			
		4656.8	7	4656.8			
		4662.7	10 d	4662.7			
		4666.6	15	4666.6	4666.66	*Cr*	1
		4669.6:	12	4669.6:			
4685.8	8 l	4685.6	8 l	4685.7	.		
N		N	30 vl	4713.18	4713.18	*He*	
		4804.3	20	4804.3			
		4823.0	15	4823.0			
4848.3	15	4847.4	25 l	4847.9:			
4855.3	8	4853.9:	20 l	4854.6:			
N	600	N		4861.63	4861.63	*Hβ*	30
4875.5	1			4875.5	.		
4924.2:				4924.2:	4924.11	*Fe*	5
4934.2:				4934.2:	{ 4934.21 / 4934.28 }	*Ba-Fe?*	6

The number of bright lines included above is 382, of which 319 were measured on the prism plates; 241 lines, or 63 per cent. of the whole number have been identified, with a pretty high degree of certainty, with 260 of the stronger lines of Rowland's table. We shall obtain a more correct representation of the facts if we limit ourselves to that portion of the prism plates which were in best focus, namely, from about λ 4060 (from which point toward violet the notes with the measures on both Flash II and Cusp II record the focus as "getting poor") to λ 4310. Here we find 230 bright lines, of which 160, or 70 per cent. are identified with 176 of Rowland's dark lines.

This large percentage of identifications was not anticipated, in view of the contrary results so far published by Sir Norman Lockyer from examinations of the eclipse plates of 1893 and 1896, nor was it realized in the preliminary examination of our own plates; on the completed reduction of the measures it appeared, however, as indisputable.

But we cannot obtain an entirely fair idea of the relationship of the bright and dark lines until we consider the percentage of Rowland's dark lines that were not measured as bright on the

plates. In the region considered, λ 4060 to λ 4310, we find in Rowland's table 66 lines of intensity 3 or over, which were not measured as bright on these plates, either because of haziness or faintness or because they were actually absent. In making this count, lines so close to others already identified as to probably merge with them on the plates are excluded, and pairs that could not be resolved by the prism train are considered as single lines. It will be recalled that a line of intensity 1 is just clearly visible on Rowland's map. If we now exclude from the above 160 lines, 55 of which were identified with dark lines of intensity less than 3, we have 105 remaining for comparison. Thus it appears that of 171 of Rowland's lines 61 per cent. were measured as bright on the plates. This represents a minimum percentage, since a special search for the missing lines would doubtless reveal many of them as faint objects on the plate. Moreover, the two plates most rich in lines had to be measured, on account of the continuous spectrum present, at some distance from the point of third contact, so that the shorter lines could not be expected to appear. Any improvement in the definition of the plates or of the exposure time would undoubtedly increase the number of bright lines found.

Hence we reach the very important conclusion that at least 60 per cent. (and probably many more) of the stronger dark lines of the solar spectrum are found to be bright in a stratum not exceeding (for the great majority of the lines) 1″, or less than 500 miles in height above the solar photosphere. There is, moreover, no reason in general to suppose that this is not equally true of the fainter lines. Therefore we may regard the existence of a reversing stratum at the base of the chromosphere as fully confirmed by the photographs.

The results here obtained are very different from those presented by Sir Norman Lockyer in his *Recent and Coming Eclipses*, p. 111. He there contrasts the 164 and 464 bright lines between F and K photographed respectively at the eclipses of 1893 and 1896, with the total number of lines, 5694, in Rowland's table for that region, and he finds the percentages 3 and

8, respectively. It is obvious that the only comparison which would be reasonable would be with the number of dark lines which his instrument would photograph just before or after totality, which would be but a small fraction of Rowland's 5694.

The chemical origin of the bright lines identified with 260 of the lines of Rowland's table is as follows: iron 102, titanium 23, chromium 11, and double assignments involving one or more of these three, as *Fe, Zr* or *Fe, Cr*, 26. Thus 62 per cent. of the lines are attributable to these three elements. Five lines are due to each of these: *Ca, Mn, V;* four each to *Ni, Sc, Zr;* three each to *H, He, Sr, La, Co, C;* two to *Ba*, and one each to *Ce, Nd*, and *Y?*. Forty-one of the lines are assigned to no element by Rowland. No particular relationship to chemical classification is apparent in these lines: *Fe, Ti*, and *Cr*, have atomic weights of 55, 50, and 52; but other elements with similar atomic weights, as *Mn, Co, Ni*, are not conspicuous by their presence.

The fewness of the nickel lines might be thought rather surprising, as Rowland places nickel second in the order of the elements in the Sun according to number of lines. This is explained, however, by the fact that there happen to be very few strong lines of this element in this particular region of spectrum.

The identification of the three lines assigned to carbon is rather dubious, so that we must consider the evidence of the plates indecisive in respect to that element.

Eight lines of the spectrum of helium would fall within the range of our plates, but only three are conspicuous, those at λ 4026.3, 4471.6, and 4713.3. The lines at λ 4120.97 and λ 4143.9 are possibly present; while those at λ 4169.1 and λ 4388.1 were not recorded. The line at λ 4922.1 would be too near the edge of the grating plate for certain detection.

Of the 66 "missing" lines of intensity 3 or over, 41 are due to *Fe*, 4 to *Ca*, 3 to *Mn*, 1 to *Ti*, 1 to *Ce*, 8 are doubly assigned (in nearly every case involving *Fe*), and 8 are not identified by Rowland. The case of manganese seems peculiar, for if we examine the missing lines over the whole range of the prism plates we find

not less than 11 strong *Mn* lines which were not measured as bright, beside some double assignments involving *Mn.* We should infer that the gaseous stratum of that element must lie very close to the photosphere.

It would be of the greatest interest to give a comparison of these results with those obtained by parties under Sir Norman Lockyer's direction in 1893, 1896, and 1898, and with those deduced from the excellent photographs of Mr. Evershed in 1898. Unfortunately, however, the wave-lengths of the lines on the spectra obtained by these observers, with a discussion of their chemical origin, have not yet been published.

These plates give no evidence of any relationship between the bright lines and the "enhanced" lines, or lines distinctly more intense in the spark than in the arc spectrum, although Sir Norman Lockyer has attached much significance to a supposed connection between them. Some of the enhanced lines are present, and others are not, or at least were not conspicuous enough for measurement. It is quite probable that they afford identifications of the chemical origin of some of the lines not assigned to any element by Rowland. Taking Lockyer's recent list[1] of enhanced lines we may perhaps thus ascribe to iron the following unassigned lines of our tables above (Rowland's intensities are added): λ 4179.02 (3), 4296.74 (3), 4489.35 (2), 4491.57 (2), 4508.46 *Fe*,– 4, 4515.51 (3), 4520.40 *Fe?* (4), 4522.80 (3), 4556.06 (3). Of the 16 remaining enhanced lines of iron in the region covered by prism and grating plates, eleven (λ 4048.76 possibly to be excepted) do not occur in our table of bright lines; four were already assigned to iron in Rowland's list, while Lockyer's λ 4351.93 appears of identical wave-length with Rowland's *Cr* line of intensity 5.

In case of titanium, for which Lockyer gives 48 enhanced lines within our limits, we may summarize the comparison as follows: 17 lines do not appear as bright on the eclipse plates; one pair is doubtful; the remainder occur as quite strong lines of the ordinary dark line spectrum, and hence would be expected to

[1] *Proc. R. S.* **65**, 452, 1900.

appear in the reversing layer, as they do. Three lines of our table not assigned by Rowland to any element may be ascribed to titanium, viz., λ 4173.71 (3), 4184.87 (2), and 4590.13 (3).

The unassigned lines at 4242.62 (2) and 4284.38 (2 N d?), may be attributed to chromium; that at 4205.24 (1) to vanadium; the comparison with enhanced lines of manganese yields no results.

The "missing" bright lines on these eclipse plates also indicated no relationship to the enhanced lines.

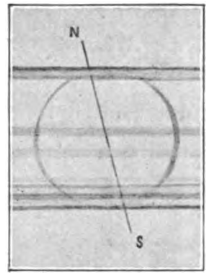
CORONAL PLATE.

Aside from the use of one red-sensitive plate, without expectation of securing any impression, but one exposure was made to the coronal spectrum, and that with the large dispersion and small range of the prism-train. If another observer had been available for working the concave grating, a plate would have been taken with it, but as the flash spectra were the particular objects of our attention, it did not seem safe to jeopardize the second flash by any further operations.

As already stated, the prism train was set at minimum for λ 4227 with especial view to securing a good image of the coronal ring at λ 4230. The exposure was begun as soon as the plate-holder could be adjusted after the exposure to the first flash, or from 5 to 10 seconds thereafter, and was continued for about 30 seconds. An exposure during the whole available time of totality would have been more suitable, in view of the apparent unusual faintness of the gaseous coronal spectrum at this eclipse.

The plate shows a very strong continuous spectrum, obviously coronal in its origin, from a source hardly more than 1′ greater in diameter than the solar photosphere. The continuous spectrum has apparently superposed upon it several longitudinal streaks of still greater intensity. This may be seen in the accompanying sketch of the appearance of the coronal ring at λ 4230, which represents the streaks and ring in approximately

their correct relative intensities on the plate. These streaks seem to bear no relation to the position of the prominences, nor can they be connected with any details of the inner corona as seen on the large scale photographs obtained by Professor Barnard and Mr. Ritchey. They were noted by Professor Campbell on his India plates, and probably by others, but a satisfactory explanation of their origin, at least in the present case, is not apparent.



No dark lines can be detected on the plate.

The plate shows most conspicuously the chromospheric arcs of $H\gamma$, $H\delta$, and the strontium radiation at $\lambda 4078$.

The strontium arc at $\lambda 4215$ is of about equal intensity with the coronal ring at 4230. The remaining arcs and rings are exceedingly faint and almost beyond measurement under a microscope, so that the determinations of the wave-lengths cannot pretend to any high degree of accuracy. In measuring the plate the settings were made on the relatively sharp, concave edges of the arcs and rings, near the position angle of first contact. $H\gamma$, $H\delta$, and *Sr* $\lambda 4078$ were the standards used in determining the constants of the formula. An approximate measure of the extent of the arc is given along with a rough estimate of its relative intensity.

MEASURES ON CORONAL PLATE.

Arc or ring	I	λ	Element	Origin
Arc 80°	20	4077.9	*Sr*	Chromosphere
Arc 90°	40	4102.0	*H*	"
Arc 80°	10	4215.4	*Sr*	"
Ring	8	4230.4	?	Corona
Ring	3	4311	?	Corona (?)
Arc 120°	50	4340.6	*H*	Chromosphere
Ring	6	4358	?	Corona

In addition to these arcs and rings faint traces of curved markings were noted at about $\lambda 4089$ (a pair?), 4137, and 4192,

but their reality is questionable, and it is not possible to estimate their extent as arcs.

The principal prominences on both limbs of the Sun are visible on this plate, and the broken appearance they give to the chromospheric arcs is in marked contrast to the uniformity of the coronal rings.

As shown by the sketch, the ring at λ 4230 is nearly of uniform intensity and shows no detail which can be brought into relationship with the large scale coronal photographs. It impressed itself upon the plate only to a distance corresponding to about 40′ from the Sun's limb.

SUGGESTIONS OF IMPROVEMENTS IN INSTRUMENTAL EQUIPMENT.

In addition to objective-prism or objective-grating cameras, it is desirable that slit spectrographs be employed, with comparison spectra of iron and titanium, in addition to the solar spectrum.

If concave gratings are employed, it is important that the plates or films should be bent to the proper radius.

Assuming that simple apparatus like that described in this paper is to be used, instead of elaborate automatic appliances, it would certainly be desirable to use a magazine plate-holder of quick action, giving a small plate to each exposure rather than several exposures on a single plate. Such a plate-holder as that described by Sir Norman Lockyer (*Recent and Coming Eclipses*, p. 87), would seem very suitable.

It would be of decided advantage in the subsequent measurement and discussion of the plates if each exposing shutter was connected with a chronograph, so that a record could be obtained of the exact instant of each exposure.

CONCLUSIONS.

In concluding this paper, which has been much more protracted than was originally intended, the principal results may be summarized as follows:

The experience, principally of Sir Norman Lockyer and Mr. J. Evershed, is confirmed, that useful results may be obtained,

without much risk of failure, by the employment of the simple objective-prism camera.

It is shown that the concave grating, used direct, without intervention of mirrors or lenses, will furnish sufficiently bright images of the flash spectra, and probably of the corona, for useful measurement and discussion.

It appears that spectra photographed with such instruments just before or after totality (within about 30 seconds of the times of contact) yield quite as valuable results as those taken at the precise instants of contact.

It is demonstrated that the stronger dark lines of the solar spectrum are in a large proportion reversed in a narrow stratum at the base of the chromosphere, and the evidence indicates that this is equally true of the fainter lines.

The differences in intensities of the bright and dark lines are chiefly due to an increase in the intensities of the former, especially for such elements as strontium, rather than to a decrease in the intensities of the latter.

The chemical origin of the dark lines which are reversed is found in elements which are among those most numerously represented in the spectrum. This tends to show that the reversal is not an inherent peculiarity of special elements, but rather a phenomenon of lines in general.

YERKES OBSERVATORY,
December 4, 1900.

CELESTIAL PHOTOGRAPHY WITH THE 40-INCH VISUAL TELESCOPE OF THE YERKES OBSERVATORY.

By G. W. RITCHEY.

THE great power of the 40-inch telescope as compared with that of the 12-inch is strikingly shown in visual observations of such objects as the dense globular star-clusters. The visual limit of the 12-inch is at about 14.5 magnitude of Pogson's scale, while that of the 40-inch is at about 16.5 or 17 magnitude. As comparatively few of the stars composing the globular clusters are brighter than the 14.5 magnitude and several thousand stars at least, in most of them, are brighter than 17 magnitude, the great difference in the appearance of these superb objects in the two instruments is readily understood. Not less important than the superior light-gathering power are the greater scale and resolving power of the larger instrument, which are necessary to show even moderately well separated the stars composing the dense central parts of these wonderful masses.

The work of measuring accurately with the micrometer the positions of a large number of stars in these clusters is very laborious; to measure in this way all the stars seen with the 40-inch telescope in such a cluster as *Messier 15 Pegasi*, for instance, would be a stupendous task indeed, especially since it is only on rare occasions of very fine seeing that the fainter stars can be seen sufficiently well for satisfactory measurement.

The fine photographs of globular clusters obtained by Scheiner, the Henry Brothers, Leavenworth, and others, with photographic refractors of moderate size, and the excellent results obtained by Keeler with the Crossley reflector show unmistakably the great value of the photographic method in the study and measurement of these difficult objects.

It seemed highly desirable to find, if possible, some way to utilize for such photographic work the great power of the 40-inch

visual telescope. In November 1899 a number of thin plane-parallel plates of glass were prepared and coated with collodion of a delicate greenish-yellow tint, which, when tested with the spectroscope, was found to effectually shut out the blue end of the spectrum, while transmitting the green, yellow, and red without appreciable diminution of intensity. Several very perfect color-screens of excellent quality and of different densities were thus secured for preliminary trials. A special plate-holder was constructed, the color-screen being mounted in the plate-holder, in contact with the sensitive plate. Cramer's instantaneous isochromatic plates are used, these being extremely sensitive to yellow light, while their sensitiveness falls off rapidly in the orange and red, on the one side, and in the green on the other, increasing again in the blue.

It will be noticed that this combination is a promising one for sharpness, as only a short region of the spectrum, for which the color-curve of the 40-inch objective is very nearly flat, is used in producing the photograph. All other rays, which are of course out of focus, and would therefore injure the sharpness, are effectually cut out, the blue by the color-screen, the red, orange, and much of the green by the non-sensitiveness of the plate for these rays. Nor is this combination an unpromising one for speed, taking into account the extreme sensitiveness of the plates for yellow light, when used with a very large and thick objective such as the 40-inch, as compared with the ordinary blue sensitive plate used with a photographic objective of the same size and thickness. Professor Vogel says that no less than 51 per cent. of the photographic light is lost in transmission through the new 32-inch photographic objective at Potsdam, although in that case the glass used was carefully selected for photographic purposes; the loss of yellow light is 33 per cent. It is estimated that between 60 and 70 per cent. of the blue light is lost in transmission through the 40-inch objective, while about 35 per cent. of the visual rays are thus lost.

It was hoped, therefore, that this combination of isochromatic plate and yellow screen, used with the 40-inch telescope,

would give very sharp photographs with reasonably short exposures. In the earlier trials of this process, which included the photographs of the cluster *Messier 13 Herculis*, plates were used which were considerably less rapid than the last lot of plates furnished by the Cramer Company, and it is confidently expected that plates still more sensitive to yellow light can be furnished soon. With the present plates, and with fine seeing, sixteenth magnitude stars are photographed with sufficient intensity for measurement with one hour's exposure. The diameter of the images of the fainter stars is less than one second of arc.

The plane-parallel color screens used in the trials of this process are 2.4 mm thick and cover a field 14 minutes of arc square at the focus of the 40-inch telescope. There is, of course, a slight radial distortion of field introduced by this form of screen, amounting for the dimensions given to about 0".03 at edge of field, where it is greatest. There is also some uncertainty introduced by the use of the collodion film, even when this is separated from the sensitive plate by only one tenth of a millimeter. The star images at edge of field are as perfect in shape as those at the center, no difference whatever being perceptible under high magnification.

A color-screen of optical glass of the proper yellow tint, and of the form of a thin concavo-convex lens, properly mounted, held by three points of its edge, in a metal plate-holder, close in front of the sensitive plate, and with the curvature of the two surfaces such that the center of curvature of each is at the optical center of the objective, would introduce no distortion of field perceptible under the most refined measurement, for fields 30 minutes of arc in diameter. Several color-screens of this form will soon be prepared for use with the 40-inch telescope. It is needless to say that for photographs intended for accurate measurement the glass used for the photographic plates themselves should be ground and polished approximately flat, as was done in the case of the plates used for the Potsdam photographs for the *Carte Celeste*.

The guiding device or sliding plate-carrier for long exposures is somewhat similar to that described by Dr. Common in *Monthly Notices*, **49**, 297; it was constructed in a very perfect manner by Mr. Johannesen, the observatory instrument maker. The plate-holder is carried on two slides, at right angles to each other, and is movable by two fine screws, the milled heads of which are held in the observer's fingers. A guiding eyepiece giving a power of 1000 diameters with the 40-inch telescope is mounted on the frame to which the plate-holder is rigidly attached; the eyepiece can be moved in two directions on this frame, so that a suitable guiding star near the edge of the plate can be found. Fine "cross-wires" of silk fiber are illuminated by red light from a small incandescent lamp mounted at the side of the eyepiece, the light being controlled by a rheostat. A light flap is arranged so that it can be turned down instantly over the plate if anything goes wrong.

By this simple arrangement the full power of the 40-inch telescope is used in guiding. This guiding, with the high power used, is very different indeed from guiding with the 12-inch telescope. Even under the best conditions incessant small movements of the image, due chiefly to the atmosphere, but partly to the instrument, render necessary continual guiding by means of the two screws which move the plate-holder. It should be noted that the greater part of these minute irregular movements could not possibly be detected with the 12-inch telescope, but are distinctly visible with the 40-inch. The plate-carrier is so light, and the slides and screws are so well made, that guiding in this way can be accomplished with very great delicacy and quickness, as compared with what could be done if the usual method of moving the entire telescope by means of slow motions were employed; this will be readily appreciated when I state that on an average no less than sixty movements of the screws per minute are necessary, even under the best atmospheric conditions. Generally as careful guiding is required under fine conditions as under ordinary ones, because the movements of the small sharp image, though shorter and less rapid, can be

seen much better than those of the nebulous image present under poorer conditions. Experience has shown that to obtain the sharpest results and the roundest possible star-images the observer must not take his eye from the guiding eyepiece nor his fingers from the screws for an instant without first turning down the flap over the plate; this is done even when the observer moves his chair and when the assistant is changing the height of the elevating floor. The flap is very useful also when sudden disturbances of any kind occur, such as those due to the slight shifting of the objective in its cell, the slight jar caused by the longitudinal slipping of the declination axis in its sleeve, and sudden blurring of the image due to atmospheric causes.

There are two evident objections to the use of such a sliding plate-holder; one is that the position of the images on the photographic plate is continually changing slightly, during the exposure, with reference to the optical axis of the objective; without proper precautions this might sensibly affect the measurability of the photographs. In the work with the 40-inch telescope the slides allow a motion of only six millimeters (about one minute of arc) on each side of the center, and there is no objection to reducing this range of motion by suitable stops to fifteen seconds of arc or less, since all that is necessary when the slides are moved to the stops is to cover the plate while the slides are brought back to the starting point, and the guiding star again centered on the cross-wires by means of the telescope's slow motions. This operation is accomplished in less than half a minute, and with the superb performance of the great driving-clock would not be necessary oftener than each half-hour, for the range suggested.

The other objection is perhaps more serious. In the work of photographing the globular clusters with the 40-inch, $3\frac{1}{4} \times 4\frac{1}{4}$ and 4×5 plates are used, so that in general the guiding star is about 2 inches, or 8 minutes of arc, from the center of the plate and of the cluster. As the zenith distance of the object is constantly changing during the exposure, there is a slight change in the amount of the differential refraction between the guiding

star and the stars of the cluster. In order that the effect of this change shall be as small as possible, the following conditions should be realized: (1) the exposure should be equally distributed east and west of the meridian; (2) for such an exposure a guiding star should be selected having as nearly as possible the same hour-angle as the object being photographed; (3) the total time covered by the exposure should be as short as possible for plates intended for measurement.

In spite of the objections named, the use of the sliding plate-holder in guiding seems indispensable with very large photographic telescopes, if the sharpest possible results are to be secured. With the 40-inch it would certainly be impossible to guide properly if the entire mass of the telescope had to be moved by means of slow motions, however perfect. Furthermore, the problem of mounting side by side, for example, two 40-inch objectives—a photographic and a visual for guiding—with such stability in their cells that there would be no relative shift of the two sufficiently large to produce a sensible change in the relative position of the photographic and guiding images at the eye-end, 63 feet away, would present very serious if not insurmountable difficulties.

A severe test of the new method is afforded in photographing such an extremely dense globular cluster as *Messier 15 Pegasi*, a fairly satisfactory negative of which was obtained on the night of October 3, with an exposure of three hours. My experience with seeing conditions during this exposure may be used to illustrate the difficulties encountered, though these conditions were better than usual. The exposure was begun with the seeing moderately good, 7 on a scale of 10. The conditions improved gradually for 130 minutes, though they were occasionally so bad for short intervals that the plate had to be covered. During the last 50 minutes of the exposure the seeing was as fine as I have ever had, the guiding star appearing as a hard brilliant point. After 50 minutes of such seeing a chill wind sprang up suddenly, which instantly destroyed the good definition; the image of the twelfth magnitude guiding star

became so large and nebulous that it was seen with difficulty and was at instants entirely obliterated.

Professor Barnard concurs in the opinion that the faintest stars distinctly shown on the resulting negative are as faint as can be seen with the 40-inch telescope under the most perfect conditions. The negative is very sharp, but would be better—the brighter stars smaller and the dense center of the cluster better resolved—if only the last two hours of the exposure time had been used; the very faint stars would be shown fully as well, as it is only under fine conditions that these photograph at all. Many faint double stars in this cluster, with magnitudes down to 16.5 or 17, and distances down to 1″, are distinctly shown and sharply separated on the negative. Multitudes of faint stars which are involved in the glare about the center of the cluster are much more easily seen on the photograph than with the telescope direct; this is true in the case of all the globular clusters.

This peculiarity is very noticeable also in the case of faint stars involved in nebulosity, as for instance, Barnard's faint double star just preceding the *Trapezium* of *Orion*, which is described by Professor Burnham in *Monthly Notices*, 49, 354, as follows: "I was unable to see the two components on any night when it was measured from the bright stars of the *Trapezium;* later on a remarkably perfect night I saw the minute pair well, though with great difficulty, and obtained a fairly good measure; as a double star it is quite unlike anything known in the heavens, and the severest possible test for the defining and illuminating power of the great (Lick) telescope; I have only been able to see it once." This star has been repeatedly photographed with the 40-inch with 45 minutes' exposure, though I have not yet had an opportunity of trying it under first-class conditions; with this exposure and with seeing 8 on a scale of 10 it is strongly shown, very distinctly elongated. Under the best conditions it should be shown well separated with an exposure of less than 45 minutes. The distance given by Burnham is 1″.3, and the magnitudes are 16 and 16.5. Eighteen stars certainly

fainter than this double are shown on the negative within a distance of one minute of arc from the center of the *Trapezium*. It should be noted that the magnitudes determined from these photographs must closely approximate those obtained visually.

On the negatives of *Messier 13 Herculis* above referred to the center of the cluster is well resolved; on the best negatives lines and groups of stars of about the sixteenth magnitude, with distances down to 1″, are well shown and distinctly separated. One of Barnard's doubles, in which the magnitude of the components is 14.5 and the distance 1″.3, is very strong, and is sharply separated; it is called by him very faint, as it is near the central glare. Burnham's double, β1199, in the heart of the cluster, discovered with the Lick 36-inch, the magnitudes being 11.4 and 12.0 and the distance in 1899, 0″.97, is markedly elongated, but is too strong with the two-hour exposure to be shown separated; that a shorter exposure would show it separated is apparent from the fact that no less than 40 faint doubles of about 1″ distance are shown distinctly separated on the negative. On the best negative of this cluster there are 3200 stars in an area 10 minutes of arc square.

The illustration of the lunar crater *Theophilus* and surrounding region (Plate XXI) is from a negative obtained with the 40-inch telescope October 12, 1900. The enlargement, as compared with the original negative, is about 6 diameters. The full aperture of the telescope was used, and the exposure time was less than one half second.

The results obtained in this work demonstrate the effectiveness and importance of telescopes of great focal length for the photography of objects requiring great scale and separating power; for dense star clusters, double and multiple stars, the surface markings of the planets, and details of the lunar surface, the gain is apparently in direct proportion to the increase of focal length. The effect of aperture, and consequent resolving power, upon the quality of photographic results is in practice so complicated with the effects of seeing conditions, accuracy of guiding, sharpness of focus, and grain of photographic plate,

that it is probable that photographic telescopes with much greater ratio of focal length to aperture than is ordinarily used, would be desirable for the photography of the classes of objects referred to.

For such purposes a photographic telescope of 2 feet aperture and 200 feet focal length is being built in the optical and instrument shops of this Observatory. Work on the optical parts, which include a 30-inch and a 24-inch plane mirror and a 24-inch concave mirror of 200 feet focal length, was begun in December 1899 and is now well advanced. This instrument is of the horizontal type, with coelostat, but differs in many details from the instrument of very similar dimensions suggested by Dr. Common in his recent address before the British Association.

In the case of the horizontal telescope of 61.5 feet focal length used by Professor Barnard and the writer at the eclipse of May 28, 1900, the ratio of focal length to aperture is 123 to 1. Exquisitely fine structure in the chromosphere and prominences is shown on the negatives obtained with this instrument, and the richness and delicacy of detail of the corona leave nothing to be desired.

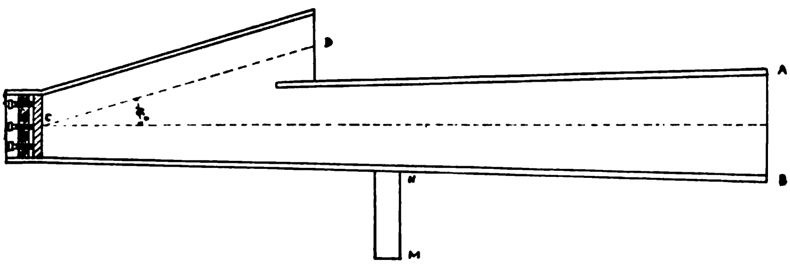
These results, obtained with a telescope of still greater ratio of focal length to aperture than that of the 200-foot, together with the stability and superb driving of this type of instrument; the high efficiency of the reflector in photography, so effectively demonstrated by Keeler; and the freedom of the reflector, when of great focal ratio, from many of the serious difficulties inherent in specula of large angular aperture: all seem to promise well for the success of the new instrument.

YERKES OBSERVATORY,
UNIVERSITY OF CHICAGO.
November 14, 1900.

THE REVERSING LAYER PHOTOGRAPHED WITH A CONCAVE ROWLAND GRATING.

By J. F. MOHLER and F. C. DANIEL.

ONE of the pieces of apparatus taken along with the Dickinson College Eclipse party on May last was a concave Rowland grating, 4 inches in diameter, ruled with 14,400 lines to the inch and of ten feet radius. It was enclosed in a box about five feet long and placed as indicated in the figure, where the grating is shown in position at *C* resting on three set screws. At *D* is an



opening 4 inches square to admit the light and provided with a tight-fitting cap. The photographic plate was placed at *A B* so that the middle of the plate would be on the axis of the grating. In this position the dispersion is nearly normal over the entire plate. At *A B* was a narrow slit about one eighth of an inch wide and seven inches long and back of the slit was a sliding plate-holder carrying a 5 × 7 Cramer instantaneous isochromatic plate. Two small wheels operated by a rod moved the plate across the narrow slit so that a series of exposures ⅛ by 7 inches could be made on the same plate. The rod was operated by an observer looking through a small objective prism spectroscope attached to the outside of the box. The box was mounted on the declination axis *M N* of an equatorial mounting so that the lines of the grating would be tangent to the edge of the Sun at the places of contacts II and III. The angle *D C E* was about

16° so that the F line of the first order came near the middle of the plate and the spectrum extended from below D_3 to above G. The equatorial mounting was supplied with a fairly good clock, which followed the Sun's image very well.

The grating was used to form a diffracted image of the Sun's disappearing crescent without the use of lens or slit, in the same way that an objective prism spectroscope is used. The focal length of the grating used in this way is just about five feet and the Sun's image is about .56 inch in diameter.

When the Sun's crescent was so thin that the dark Fraunhofer lines could be distinctly seen in the prismatic spectroscope, which was about thirty seconds before totality, the cap was removed from *D* and a series of exposures of about one second each was made until the "flash" spectrum had disappeared. The plate was then moved forward a little and kept in position for about ninety seconds. The plate was moved forward again and another series of exposures made to catch the flash at third contact.

The results obtained were not quite as good as we had expected. The plate lacked in sharpness of definition. We had, however, timed the exposures nearly right and obtained about forty bright lines at the flash and perhaps sixty dark Fraunhofer lines on exposure before totality and only three distinct lines during totality. The measurement of thirty-two of the bright lines is given in the table below. This table gives the measured wave-length, the intensity of the bright line, and the element supposed to produce it. This last is taken from Rowland's table (this JOURNAL, Vol. I). Our measurements are only to Ångström units, as the lines were not sufficiently sharp for more accurate measurements.

The lines D_3, F and $H\gamma$ are by far the strongest lines in the flash, and also appear as strong lines in the long exposure made during totality. They appear on the plate as images of a prominence near the eastern limb of the Sun, and are of different shape for the light coming from the western limb of the Sun, both sets of images appearing on the same exposure. The

exposures made at the end of totality did not give as good results as the exposure to the first flash, as the position of the instrument had been altered a little in declination in moving forward the plate.

TABLE OF LINES SHOWING AT THE FIRST FLASH.

Line	Intensity	Measured λ	Substance	Line	Intensity	Measured λ	Substance
$H\gamma$	12	4340	*H*		2	4638	*Fe*
	1	4376	*Fe*		2	4644	*Fe*
	1	4383	*Fe*		1	4654	*Fe*
	1	4395	*Ti*		1	4662	*Fe*
	2	4417	*Ti*		1	4666	*Ti* (*Fe*)
	2	4442	*Fe*	F($H\beta$)	15	4861	*H*
	2	4470	*Fe*		1	4920	*Fe*
	2	4471	*Ti*		2	4923	*Fe*
	1	4502	*Ti*		1	4933	*Fe*
	1	4534	*Ti Co*		1	5017	*Fe Ni*
	1	4550	*Fe Ti Co*	b_4	2	5167	*Mg Fe*
	1	4556	*Fe Ti*	b_3	2	5169	*Fe*
	2	4563	*Ti*	b_2	3	5173	*Mg*
	2	4571	*Mg*	b_1	4	5184	*Mg*
	2	4582	*Fe*	1474 K	2	5316	
	1	4630	*Fe Ti Co*	D_3	10	5876	*He*

Although our list of lines is not extensive, and the accuracy of measurement only one Ångström unit, nevertheless the results lead us to think that very good results could be obtained in this way.

The lack of sharpness of the lines may be due to one or more of four causes:

1. The location should be such that the lines of the grating, when perpendicular to the Right Ascension circle, will be tangent to the disappearing and reappearing crescent of the Sun at contacts II and III. We were situated at the village of Pungo, Va., very near the central line of totality, but we did not make any observations for position. We arrived at Pungo on Friday, May 25, and the rain all day Friday and Saturday gave us short time to set up the instruments; we had no time for latitude and longitude observations, and no time to change position if we had found change desirable. Of course we could make the lines of the grating tangent to the Sun's crescent at

either contact II or III by giving the grating the proper inclination, but to get it tangent to the Sun at both contacts the instrument must be situated on the central line of totality.

2. With this form of mounting, the clock must follow exactly the motion of the Sun, as any drift in R. A. will spread out the lines. In trials with the instrument before the eclipse the clock was running just about right. All these trials were made without the plate-holder in position, and when the plate-holder was put on the end of the box the instrument was so exactly balanced in R. A. that there was not enough weight either way to take up the lost motion of the driving-screw, and for that reason the lines show some irregular drift in the successive exposures.

3. The focusing of the grating must be done with a collimator, and while this had been accomplished before leaving Carlisle, we found that it had to be repeated when we arrived at Pungo, where with the facilities at hand the work could not be done very accurately. The plate may have been, and doubtless was, somewhat out of focus.

4. The astigmatism of the grating: This property of the concave grating has doubtless been the cause of its rejection for this class of work, and the substitution of the objective prism. The amount of astigmatism has been worked out by Dr. S. A. Mitchell [*Johns Hopkins Circular*, June 1898], and for a point source of light is given by the formula:

$$a = -Z + Z\sqrt{r\left(\frac{\cos\gamma + \cos\mu}{\rho} - \frac{1}{R}\right)},$$

where a is the length of the image of the point, Z the length of the lines on the grating, r the distance of the image from the grating, R the distance of the point source of light from the grating, ρ the radius of grating, and μ and γ the angles of incidence and reflection. Using the grating as we did, $\mu = 0°$, $R = \infty$, $r = \frac{1}{2}\rho$, therefore

$$a = -Z + Z\sqrt{\frac{\cos\gamma + 1}{2}}.$$

Now if $\gamma = 16°$ and $Z = 1\frac{1}{2}$ inches, $a = .015$ inch.

The image of the Sun with a mirror of this radius is about .56 inch in diameter. With a slit ⅛ inch wide, the extreme blurring at the edges due to this cause would be .0096 inch, and in the middle of the strip the widening of the lines would be only .0004 of an inch. With a slit $\frac{1}{16}$ of an inch wide the spectrum would still be wide enough to measure easily, and the extreme blurring would be less than .003 of an inch; lines as fine as this are nearly as good as can be obtained on a rapid photographic plate.

If no slit at all is used, and the Sun's entire image is photographed, the astigmatism would blur the edges at the poles about .03 of an inch, *i. e.*, there would be a shading .015 of an inch wide above and below the true image. This effect might be made less by using a grating of fewer lines to the inch, or by using light of shorter wave-length. The great advantage of using a concave grating in this way is that there is nothing in the instrument to absorb the radiations coming from the Sun. In common with the objective prism it has the disadvantage that no comparison spectrum can be photographed alongside of the solar lines, but it has the advantage over the prismatic spectroscope that the spectrum is normal. Our partial success leads us to believe that the instrument could be used to great advantage in obtaining the spectrum of the flash.

DICKINSON COLLEGE,
October 26, 1900.

FIRST RESULTS OF INVESTIGATIONS ON THE OBSERVATION OF THE SOLAR CORONA WITHOUT AN ECLIPSE BY MEANS OF THE HEAT RAYS.[1]

By H. Deslandres.

The corona, which is the highest, the most extensive, and the most mysterious portion of the solar atmosphere, has not hitherto been observed without a total eclipse. However, several attempts have been made to observe and to photograph it under ordinary conditions, in particular by Sir W. Huggins in 1885, by Messrs. Hale and Riccò in 1893 and 1894, and by myself from 1891 to 1893.

In February 1894 (*Bulletin Astronomique*, p. 66) I described a new method of accomplishing the result. The previous attempts had been made with the visible and ultra-violet rays; but these rays are too intense in the diffuse light of our sky, which is the obstacle interposed between us and the corona. However, for reasons too long to be repeated here, the difficulty is considerably diminished with the extreme infra-red rays. In brief, the daily observation of the corona is dependent upon the practical registration of images formed by the heat rays alone.

In 1895, Mr. Hale, adopting these ideas, constructed for the study of the corona a differential apparatus, consisting of two very delicate and sensitive bolometers. The apparatus measures, at a given point of the sky, the heat emitted by the corona, augmented by a considerable amount of diffuse atmospheric heat, but it has not yet given any certain result on the corona.[2]

For my part I pursued my first idea. The infra-red radiation of our sky is faint, but, on the other hand, is the infra-red radiation of the corona marked? I proposed to measure it at

[1] *Comptes Rendus*, 131, 658, 1900.

[2] Mr. Hale's experiments were made at the time of maximum Sun-spots, when the corona has the same intensity and the same extent at all points of the solar circumference. Hence, probably, the cause of failure.

he total eclipse of 1896 in Japan. I constructed for this purpose a very simple apparatus, consisting of a thermo-electric pile, which could not be used on account of the bad weather. I employed this same apparatus for the same investigation during the eclipse of May 1900, in Spain, with the aid of M. Charbonneaux, assistant astronomer (see this JOURNAL 12, 287). The infra-red radiation near λ 1.3 μ was found to be considerable, amounting to as much as from one half to one third of the radiation of the same points in the sky after the eclipse, at an elevated station where the air, it is true, is remarkably pure and dry. This result indicates the possibility of obtaining the corona under ordinary conditions with the heat rays alone.

Upon my return I employed at Meudon, where the sky is, however, less favorable, the same apparatus and a similar apparatus for the daily study of the corona, with the constant aid of M. Charbonneaux. I now present the first results, which are of slight importance, but at least show the value of the method.

The eclipse apparatus comprised: (1) a mirror of 0.30m aperture and 1.50m focal length; (2) a slit spectroscope, with lenses and prism of crown glass; (3) a sensitive Melloni thermopile; (4) a Deprez-d'Arsonval galvanometer, not very sensitive, but dead-beat, with constant zero, simple and easily manipulated. The collimator slit was 12mm high and 1mm wide; the thermopile received only the infra-red heat from the region between λ 1 μ and λ 1.8 μ.[1]

At Meudon the Melloni thermopile has been replaced by a Rubens thermopile, and the collimator slit by a circular aperture

[1] These details aid in explaining the cause of the differences between our results and those of Mr. Abbot, who also measured the heat of the corona at the same eclipse with a very sensitive bolometer. In his apparatus the radiation passes through no glass or other absorbent and comprises all the high and low temperature rays (*tous les rayons de haute et basse température*) from 0.5 μ to 60 μ at least. Our measure, on the contrary, involved only the high temperature rays. Mr. Abbot obtained negative deflections for the center of the Moon and the inner corona, and concluded from this that the corona is colder than the bolometer. Now the corona certainly emits intense red and yellow rays, which give strong positive deflections with a sensitive bolometer. The low temperature rays, which give negative deflections, must be still more intense. (*Il faut que les rayons de basse température à déviation négative soient plus intenses encore.*)

4mm in diameter. The Sun was displaced with reference to this aperture so as to permit measurements to be made of the heat at points 3′ of arc apart on the same diameter at distances from the limb ranging from 5′ to 20′. It has been found, at all hours of the day, that the sum of the deviations measured on the solar equator is uniformly greater than the corresponding sum on the line through the poles. This characteristic difference has been ascribed to the corona, which at present is of the form peculiar to the Sun-spot minimum and is more intense at the equator than at the poles.[1]

In a second apparatus the 4 mm aperture has been replaced by an opening 1 mm in diameter, the prism has been discarded, and the beam projected directly upon the linear thermopile by means of a cylindrical lens. The thermopile received the rays lying between 0.5 μ and 2.8 μ (limit of transparency of the glass). The results in the second series of experiments have been the same as in the former case. I give here a table showing the total deviations measured in the four principal directions.

	Pole		Equator	
	North	South	East	West
September 26	21.0	22.7	26.4	24.0
September 27	23.0	21.5	25.5	27.0
October 3	22.8	21.2	27.8	27.9
October 5	22.2	21.7	28.6	28.8
October 6	23.8	22.3	27.8	28.1

As a systematic error due to the position of the receiving apparatus might be feared, this apparatus (support of the aperture, cylindrical lens, and thermopile) was turned through 90°, the aperture remaining fixed.[2] The results remain the same.

[1] It must be assumed that the diffuse heat of our atmosphere is uniformly distributed around the Sun.

[2] We have also avoided all chance of error due to a possible variation in the diffuse heat of our atmosphere by measuring several times, during the experiment, the heat emitted by a given point of the sky.

The differences detected thus seem to be really due to the corona and would be the first manifestation of the corona without an eclipse.

But these results, obtained with crude and inexpensive apparatus, are incomplete. To make further advances it would be necessary to have a more sensitive galvanometer, to provide for the rotation of the receiving apparatus about the center of the Sun in order to avoid loss of time, to measure only the infrared heat outside of the absorption bands of water-vapor, and to attempt a photographic registration of the deflections, from which an image of the corona could be built up point by point.

However, direct photography of the images formed with the infra-red rays, which has not yet been accomplished, is alone capable of furnishing a complete solution; it would give at the same time the lower part of the solar atmosphere (chromosphere and prominences) more simply than the classic method of the spectroscope.

THE HEAT RADIATION OF THE CORONA.

By S. P. LANGLEY.

IN a preliminary account of the Smithsonian observations of the eclipse of May 28, 1900,[1] I mentioned that although previous efforts had been made to ascertain the heat of the corona, the bolometric measures then taken were probably the first which had really shown it, but the brief description given of the work perhaps did not convey to the reader the full import of the observation.

Long work upon the Moon with the bolometer by me, in former years, had led to an improvement of the instrument and developed skill in its use. At the time of the eclipse it was capable of indicating a deflection of several thousand bolometric degrees, but its sensitiveness was intentionally reduced until it gave a deflection upon the full Moon of only 85 such degrees, as is shown by measurements since the observation.

Now the inner corona is well known from visual observation to be intrinsically much brighter than the full Moon, and if its heat were proportionate to its light, it should give a deflection of at least something over a hundred bolometric degrees. It gave, however, a deflection of only five such degrees.

The reader cannot but have noted, in the great photographs obtained by the 135-foot lens loaned by Professor Pickering, the appearance of what so much resembles an electric discharge around the poles. It is by no means here shown for the first time, but perhaps never with more distinctness.

I do not mean to say that the corona is such an electric phenomenon, and not formed of incandescent matter, gaseous or solid. On this point evidence is still incomplete, yet the present observations seem to bring some additional evidence in favor of the first view, for the absence of heat is obviously

[1] *Science*, June 22, 1900.

consonant with it, and it is supported by independent studies of the glow discharge.[1]

I may add that the bolometer, however trustworthy an instrument, demands an installment in a chamber of uniform temperature, with much accessory apparatus for its best effect, and that this was provided for it on the present occasion. What is still more important, it, like any other apparatus of the kind, should be in the hands of one long familiar with it, to give reliable information at a time so brief and trying as that of totality. While I have familiarity myself in its use, yet considering that Mr. Abbot was in more continuous recent practice, I assigned the observation to him, and I have all the confidence in its results that I should have, had I made it myself.

[1] It is well known that Ångström found ("Strahlung verdünnter Gase," *Ann. der Phys. und Chem.*, 48, 493, 1893,) in 1893, that the glow discharge had no infra-red spectrum, and Wood found ("Experimental determination of temperature in Geissler tubes," *Physical Review*, 4, 191, 1896,) that the temperature of the glow discharge was only some 15 or 20 degrees Centigrade above that of the surroundings.

ON SOME ATTEMPTS TO DETECT THE SOLAR CORONA IN FULL SUNLIGHT WITH A BOLOMETER.

By GEORGE E. HALE.

DURING the last seven years I have made many attempts to detect the solar corona in full sunlight. In spite of the negative outcome of these experiments it may serve a useful purpose to summarize them here, particularly as results widely different from my own have been published by M. Deslandres.[1]

The method employed in my earlier work was a photographic one, requiring the use of a spectroheliograph adjusted for the K line. The principle of this method, and the experiments made by its aid on Pike's Peak in 1893 and on Mt. Etna in 1894 have been described elsewhere,[2] and need not be given here. Suffice it to say that no images which could reasonably be regarded as representing the corona were secured.

After Professor Riccò had completed his tests of the photographic method it was decided that little or nothing could be expected from further attempts of this kind. The possibility of sufficiently increasing the contrast between the corona and sky by the use of the dark K line or in any other known way did not appear promising, and I accordingly turned my attention toward the development of an entirely different method, based upon the use of a bolometer or some similar heat-measuring instrument.

A full description of this method was published in 1895.[3] The essential principle involved is not the use of the less refrangible rays of the spectrum, but the employment of a heat-measuring instrument giving deflections proportional to the energy received. Assuming the sky radiation at a given distance from the Sun to have the same intensity at all position

[1] See p. 366.

[2] HALE, *Astronomy and Astro-Physics*, October 1894. RICCÒ, ASTROPHYSICAL JOURNAL, 1, 18, 1895.

[3] ASTROPHYSICAL JOURNAL, 1, 318, 1895.

angles, it is evident that the sky deflection may be taken as the scale zero, and hence that the relative radiation of any two parts of the corona may be measured as readily in full sunlight as at times of total eclipse.

The instruments used in successive years are enumerated below. In all of the experiments I have had the efficient assistance of Mr. Ferdinand Ellerman.

1895. Silvered mirror of 24 cm aperture and about 2 m focal length, mounted equatorially. Platinum bolometer 4 mm long, 0.5 mm wide, mounted radially in water jacket. Both arms exposed, one to corona, the other to sky beyond corona. Rubens-Du Bois galvanometer, with light needle system. Different deflections were obtained at different position angles, but they were subsequently found to be due to instrumental causes.

1896. Silvered mirror of 60 cm aperture and 18.6 m focal length, used with a large heliostat. Platinum bolometer 30 mm long, 4 mm wide, mounted in radial slot in heavy cast-iron drum, surrounded by water jacket, with central hole through which rays forming 17.5 cm solar image passed freely. Both arms exposed, as above. Rubens-Du Bois galvanometer. Different deflections were observed at different position angles, but these were traced to the effect of rotating the bolometer, and were not considered coronal.

1898. Forty-inch refractor. Compound bolometer having in each arm 5 platinum strips 35 mm long and 0.8 mm wide, in water jacket. Bolometer arms radial, centers equidistant from center of Sun and 22 mm apart, both exposed to corona. Rubens-Du Bois galvanometer. In this case my hope was to detect the edge of a coronal streamer as the bolometer passed over it. The deflections should occur in pairs, a positive deflection being followed by a negative one. No results that could be surely attributed to the corona were obtained.

1899. Laboratory experiments with the bolometer used in 1898 showed that a faint artificial corona could be detected as easily when projected upon a very bright background as when observed alone.

1900. The apparatus used at the total solar eclipse of May 28 consisted of a silvered mirror of 50 cm aperture and 8.1 m focal length, used in conjunction with a coelostat; and a platinum bolometer 10 mm long, 1 mm wide, in water-jacket, one arm exposed. The bolometer remained at rest, and the radiation from a radial strip at any position angle in the corona could be brought on to the bolometer by the aid of a rotating drum, containing a suitable combination of mirrors. The galvanometer was an exceedingly sensitive one made by Dr. Mendenhall. As has been previously stated,[1] no measures were obtained during the total phase, but just after totality no difference could be detected between the radiation of the Moon and that of the corona.

The following conclusions may be drawn from the observa tions made during the course of this investigation:

1. The heat radiation of the sky near the Sun, under excellent atmospheric conditions, is many hundreds of times greater than that of the corona. As a differential method has been used in most cases, no actual measures of this radiation can be given, but the above statement, based on deflections observed when balancing with a shunted galvanometer, may be regarded as a very conservative one.[2]

2. The heat radiation of the corona is very small—much less in proportion to its light than that of the full Moon. The best evidence I obtained of this was during the partial phase of the eclipse, when no difference was detected between the radiation of the dark Moon and that of the corona.

3. The small intensity of the coronal heat, as measured by Mr. Abbot during the recent eclipse, fully accounts for the

[1] ASTROPHYSICAL JOURNAL, 12, 88, 1900.

[2] A *maximum* value of the ratio of the coronal heat to that of the sky, deduced from Mr. Abbot's measures before and during totality, is about $\frac{1}{11000}$. The measure of the sky radiation here employed was made about five minutes before second contact, and is certainly much less than what would have been recorded in full sunlight.

I am unable to understand M. Deslandres' explanation of this result as due to "negative-deflection-giving rays." If the corona emits rays which have the power of annulling the heating effect of ordinary radiations, why does M. Deslandres obtain the same results with and without a prism?

failure of my attempts to detect the corona in full sunlight. In spite of the extreme sensitiveness of my instruments, they were not capable of detecting the minute difference between corona and sky.

4. On account of the uniformity of the sky radiation under good atmospheric conditions, and the success of the experiments made with an artificial corona, it appears probable that the method will ultimately give a means of determining at least the approximate form of the corona in full sunlight.

5. This method should not be confused with M. Deslandres' plan of photographing the corona by the exclusive use of the infra-red rays, as the essential principle is entirely different in the two cases.

The work is being continued at the Yerkes Observatory with the aid of the extremely sensitive radiometer recently used here by Professor Nichols in his researches on the heat radiation of stars and planets.

YERKES OBSERVATORY,
December, 1900.

REMARKS ON MR. EASTON'S ARTICLE "ON A NEW THEORY OF THE MILKY WAY" IN THE *ASTROPHYSICAL JOURNAL* FOR SEPTEMBER.

By H. Seeliger.

In my paper entitled "Considerations on the Distribution of the Fixed Stars in Space,"[1] I have called attention to a fallacy which has been employed in the explanation of the surprising accumulation of stars in certain regions of the Milky Way in the immediate neighborhood of regions very deficient in stars, or in the explanation of the other fact that quite starless regions occur within portions of the Milky Way which are pretty uniformly occupied by stars. As many of the readers of this Journal will perhaps not see this paper, I take the liberty of repeating here the part referred to, quoting literally the main point at issue: "No reasons of a general nature can be assigned why an annular arrangement of the accumulations in the Milky Way is *a priori* any more probable than any other distribution. This has to be especially mentioned because the opinion has been expressed by others that the occurrence of bright and hence dense accumulations, in the immediate neighborhood of starless or empty regions, indicates with a great degree of probability that these accumulations must have a relatively small extent in the line of sight, because otherwise we should have to assume that there were cylindrical vistas which were all turned toward the Sun in a most improbable manner. This argument is, however, based upon an error, for it can readily be seen that with a given number of stars the probability for any given apparent distribution, and hence for the occurrence of certain definite vistas, is entirely independent of the dimensions of space in the line of sight. A few words will now be given to this subject in order to dispel any lack of

[1] "Betrachtungen über die raümliche Vertheilung der Fixsterne," *Abhandlungen der bayer. Akademie der Wissenschaft*, München, 1898, p. 628.

clearness on this really important point. Let N be the number of those stars of the Milky Way which appear to be within a large area of the heavens $d\Omega$, and which therefore are actually situated within a conical space R, the vertex of which is at the observer. If $d\omega$ is a small portion of the sky lying within $d\Omega$, and K is the conical space corresponding to it, then the probability that, with an accidental distribution of the stars, just n of the N stars will appear to lie within $d\omega$ will be

$$W_n = \frac{N \cdot N-1 \ldots N-n+1}{1 \cdot 2 \ldots . n} \left(\frac{K}{R}\right)^n \left(1 - \frac{K}{R}\right)^{N-n} \ldots\ldots \quad . \quad (1)$$

This formula is the more exact the smaller the total volume of the stars in comparison to the volumes of space coming into consideration. In view of the exceedingly sparse distribution of the cosmical masses in space, it may therefore be considered as almost absolutely correct. In order to direct our attention to the general case, R may consist of a series of frusta of cones which are bounded by spheres with the radii r_0 and r_0', r_1 and r_1', etc., and with the center at the observer.

Then

$$R = \frac{d\Omega}{3}\left[(r_0'^3 - r_0^3) + (r_1'^3 - r_1^3) + \ldots .\right].$$

$$K = \frac{d\omega}{3}\left[(r_0'^3 - r_0^3) + (r_1'^3 - r_1^3) + \ldots ..\right].$$

and $\dfrac{K}{R} = \dfrac{d\omega}{d\Omega}$ is, like W_n, *entirely independent* of the dimensions in the line of sight. It is a matter of complete indifference in the question of probability whether the *same* number of stars is spread out in the direction of the line of sight or is compressed into a small space."

I had thought that this discussion had made this very simple matter entirely clear. I was therefore not a little surprised to learn that Mr. Easton had raised objections to it (*loc. cit.*, p. 150). A quarrel as to the correctness or incorrectness of such simple mathematical considerations is obviously entirely impossible, and I only regret that I have to refer to this here. Nevertheless, after this experience it seems to me that a few other remarks may be in order.

I first beg to state that my mode of presentation is *not* drawn from J. Herschel. The citation from the "Outlines" made by Mr. Easton was hitherto entirely unknown to me. This citation, however, can prove nothing else than that Herschel also was a victim of the same serious blunder as many other astronomers after him. It is very interesting psychologically and invites further inquiries as to how it is possible that so simple a blunder could be made by different individuals quite independently of each other. It would appear to me that in this case an incorrect appreciation of the principles of probabilities is associated with the adoption of certain preconceived opinions as to the correctness of which a decision is impossible in advance.

If we know nothing as to the manner of the origin of a given constellation of stars in the heavens, which is actually the case, we may, on the assumption that this constellation originated by accident, keep within the limits of our knowledge, and hence apply the principles of probabilities, that is, we may speak of the probability of the constellations coming into existence.

If we now arrange a given number of stars in constellations, each arrangement is as probable as any other. It is therefore equally probable that these stars lie within an accurate circle or polygon, or in any more complex or irregular curve.

It is well known how much persons with an incomplete mathematical education are accustomed to object to this consequence of the elementary principles of probabilities, although probably no one would dare to doubt its correctness.

A correct application of this principle is obtained even in complicated cases by the laws of probabilities, which, in the case mentioned above, lead to the universally known formula (1). In this formula there only appears the quotient $\frac{K}{R} = \frac{d\omega}{d\Omega}$, whence follows the indisputable theorem that W_n is entirely independent of whether the N stars are distributed according to the laws of chance in a space of great or small extent in the line of sight. But, on the other hand, the expression (1) shows

W_n is in a high degree dependent upon n. We know that for a small value of n, W_n is relatively small, and with increasing n at first increases very rapidly, then more slowly until at about $n = N\frac{K}{R}$ it reaches a maximum, and from there it decreases, at first slowly and afterwards more rapidly. It also follows that the occurrence in the Milky Way of dark places in the midst of stellar accumulations is indeed very improbable, but in every case *the probability remains just as slight if we compress the same number of stars into a smaller space*, if this covers the same portion of the heavens as before. If anyone questions this result, he questions the fundamental principles of probabilities and commits a blunder, since we are here concerned with such exceedingly simple considerations. The most trivial illustrations can be cited in which similar relations occur.

If a great number of trees are planted in a ring-shaped area, and if we may assume that they were distributed at random, then the probability of the occurrence of cylindrical vistas— for an observer at the center of the circle, is entirely independent of whether the same number of trees stand in a broad ring or are compressed into a narrower ring. This is true as long as the trees are not too thick in comparison to the dimensions of the space at disposal.

The condition of things is changed, however, if we wonder at the actual occurrence of such very improbable irregular distribution of stars in the sphere, and seek for causes which might reduce this improbability. But the problem in probabilities proposed above, and treated by me, has nothing whatever to do with this question. It is possible that dynamical, physical, or other points of view, may lead to the understanding that a pronounced compression of the stars in space may favor the development of bright and dark places in the Milky Way; indeed, I cannot deny that such a suspicion is natural. But this is not discussed either by J. Herschel or by Easton; indeed, such assumptions seem to have unconsciously crept in as preconceived opinions, as I have already suggested above. If particular

reference had been made to this possibility, the criticism of an error in logic would not have applied, but in the present state of our knowledge only unproven and easily assailable suspicions could be expressed. If it should become possible to avoid the latter, this would signify an important step in the progress of stellar astronomy.

MUNICH,
October 15, 1900.

Minor Contributions and Notes

APPOINTMENT OF PROFESSOR W. W. CAMPBELL AS DIRECTOR OF THE LICK OBSERVATORY.

At a meeting of the Board of Regents of the University of California, held on December 11, the previous action of the Observatory Committee in appointing Professor W. W. Campbell as Director of the Lick Observatory was approved by unanimous vote. The wisdom of this choice will be apparent to everyone familiar with the circumstances of the case. The task which falls to the successor of Professor Keeler is no easy one, a fact which the Observatory Committee fully appreciated. They accordingly deferred action until the opinions of many eminent astronomers in this country and abroad could be secured. The replies, almost without exception, named Professor Campbell as first choice. It is evident that his remarkable success as an investigator, his tireless energy, and his ability to direct the works of others are widely known and appreciated. It is a pleasure to extend congratulations to the President and Regents of the University of California for the wise manner in which the appointment was made, to the Lick Observatory for its bright prospects under such leadership, and to Professor Campbell himself for the wider opportunity in the prosecution of his researches which he will now enjoy.

Striking evidence that the new Director's administration will be a progressive one is contained in the announcement which appears almost simultaneously with the news of the recent appointment. At Professor Campbell's request Mr. D. O. Mills, the donor of the Mills spectrograph, has given the sum of $24,000 to meet the expenses of an expedition to the southern hemisphere. The purpose of the expedition is to extend to the remaining naked-eye stars of the southern hemisphere Professor Campbell's well-known investigations of motions in the line of sight, the results of which have been published in this Journal. Preparations for this important work are going rapidly forward at the

Lick Observatory. It is understood that a station will be selected in Chile or Australia, and that the members of the party will remain at least two years after the instruments are ready for observations. The entire investigation, which is nearing completion for the northern stars, will involve the determination of the velocity in the line of sight of all stars down to the fifth magnitude.

G. E. H.

INDEX TO VOLUME XII.

SUBJECTS.

For titles of Reviews see Table of Contents.

INDEX TO VOLUME XII.

AUTHORS.